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SYLLABUS

OF

A COURSE OF LECTURES

ON

PHYSIOLOGY

BY

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In delivering my first course of Physiology last year, I adopted the plan of placing before my class at the beginning of each lecture a short written summary of its contents. The papers written for this purpose were called Programmes. As I believe they were found to be useful I have now printed them. They have been revised and rearranged, but want of time has rendered it impossible to make additions.

I have thought it desirable to place the descriptions of the "immediate principles" referred to in the Lectures under one heading, and to print them at the beginning. The descriptions although very short will be found sufficient to enable the student to connect his physiological with his chemical teaching.

J. B. S.

University College,
October, 1875.

SYLLABUS OF A COURSE OF LECTURES

ON

PHYSIOLOGY.

STŒCHIOLOGY.

Carbonic Hydrates.

Cellulose. The material of the outer membrane of the plant-cell is unaffected by dilute acids or alkalies but is converted by strong sulphuric acid into a body which is coloured blue by iodine.

Starch is the chief constituent of the "Starch grains" contained in the cells of plants; in these grains it is enclosed in concentric envelopes of cellulose; it is soluble in water, the solution being opalescent; it is coloured blue by iodine; the blue colour disappears on heating but reappears on cooling unless the heating has been long continued. Starch is converted by prolonged action of weak acids into Dextrin (a body which is coloured red by iodine) and eventually into grape sugar. It is converted in presence of diastatic ferments, *e.g.* those of the salivary glands, pancreas and liver, into grape sugar. *Glycogen or animal starch* exists in quantity in the cells of the liver, (especially during digestion) in muscles and in all embryonic tissues; it is soluble in water the solution being opalescent, and coloured brown or reddish-brown by iodine; it is readily transformed into grape-sugar in presence of the diastatic ferments; as contained in the liver it undergoes this change immediately after death. Glycogen is obtained in quantity, by throwing the rapidly comminuted liver of an animal just killed during the period of greatest digestive activity of the organ, into boiling water slightly acidulated with acetic acid. From the pale yellow filtered and concentrated extract, glycogen is precipitated by the addition of alcohol.

Milk Sugar or Lactose ($C_{12} H_{22} O_{11}$) constitutes about 15 per cent. of the solids of milk : it can be obtained directly from whey after separation of albuminous compounds by crystallization in rhombic prisms; it is converted by the prolonged action of weak acids into grape sugar; it is transformed very readily into lactic acid, under the influence of a ferment always present in milk.

[*Lactic Acid* ($C_3 H_6 O_3$), a syrupy, nearly colourless acid liquid, Sp. G. 1·215. It exists in all milk, in which the transformation of milk-sugar begins immediately after it is drawn; also in gastric juice, in chyme and in all farinaceous liquids which have turned sour. Bunches of crystals of zinc-lactate are obtained by immersing a plate of zinc in sour whey which has been freed of its albuminous compounds.]

Inosite or Muscle sugar ($C_6 H_{12} O_6$) exists in all muscle, and occurs pathologically in the urine in uræmia; it differs from grape sugar in not affecting polarized light, in not reducing metallic oxides, and in being incapable of alcoholic fermentation. When a solution of inosite is evaporated with nitric acid in a porcelain capsule, then moistened with calcic chloride solution and again evaporated after the addition of a little ammonia, a bright rose coloured patch remains (Scherer's test). When the aqueous extract of muscle from which the creatin has been crystallized out (see creatin) is precipitated by lead acetate, a filtrate is obtained in which the presence of inosite can be proved by the above test. It crystallizes from its solution in alcohol in long rhombohedra.

[*Sarcolactic acid.* A body having the same composition and the same physical properties as lactic acid of milk, but differing from it in its constitution and in the solubility and crystalline form of some of its salts. It is contained in the alcoholic extract of the concentrated water extract of flesh from which the creatin has been crystallized and separated. The method (Scherer's) consists in evaporating the alcoholic extract, distilling the residue with dilute sulphuric acid, so as to get rid of the volatile acids present, then digesting the product with 8 times as much strong alcohol for a day or two, filtering and concentrating the filtrate, heating the residue with milk of lime and reducing it to dryness. By extracting this with water a solution of calcic lactate is obtained, which after precipitating the excess of lime by CO_2 is nearly pure.]

Grape Sugar or Glucose or Starch Sugar ($C_6 H_{12} O_6$) occurs in extremely small quantity in blood, muscle, and other tissues, and (according to Brücke) in normal urine. It is distinguished by its power of reducing certain metallic salts, by its action on polarized light, by its splitting, when subjected to the action of the yeast-plant at a suitable temperature, into alcohol and carbonic acid, and by its yielding lactic acid in presence of albuminous bodies in process of putrefaction. It is soluble in 1½ parts of cold water, and to any extent in boiling water. From its solution in boiling alcohol, it readily crystallizes. On the power of reduction possessed by grape sugar depend the two most important tests:—"Trommer's Test" consists in adding solution of potassic hydrate to the liquid supposed to contain sugar, and then weak solution of cupric sulphate, so long as the precipitate of cupric hydrate first formed redissolves on agitation *and no longer.* On gently heating, a yellow precipitate is formed of cuprous hydrate, or a deposit of cuprous oxide. In applying this test, the original method as above described, may be advantageously modified as follows:—To a small quantity of ten per cent. solution of sulphate, add the liquid to be tested; then caustic potash guttatim until the solution is clear, and heat gently. In the other test (Böttger's) instead of cupric sulphate, a small quantity of white bismuth is added. On boiling, metallic bismuth falls as a black powder.

FATS.

Palmitin ($C_3 H_5 (C_{16} H_{31} O)_3 O_3$) and *Stearin* ($C_3 H_5 (C_{18} H_{35} O)_3 O_3$), which in solution in olein constitute animal fat, are insoluble in water, soluble in hot alcohol, ether, chloroform, benzole, &c. Under the influence of super-heated steam they are decomposed, taking up water and yielding glycerine and Palmitic and Stearic acids respectively. ($C_3 H_5 (C_{16} H_{31} O)_3 O_3 + 3 H_2 O = C_3 H_5 (H_3) O_3 + 3 C_{16} H_{32} O_2$.) A similiar change takes place more gradually under the influence of pancreatic secretion in the intestine, as well as in presence of albuminous bodies in putrefaction. Alkaline palmitates and stearates (Soaps) are obtained when fat is dissolved in potash or soda with the aid of heat; such soaps exist in bile. When fat becomes rancid, it not only undergoes transformation into acids and glycerine, but takes up oxygen, in consequence of which volatile and pungent acids belonging to the same series ($C_n H_{2n} O_2$) but containing less carbon are formed.

Palmitin fuses at 40°C, Stearin at about 60°C. According to the proportion in which they exist in different kinds of fat, the fusing points of such fats vary. Thus while beef fat fuses at 37°C. and contains three parts of Stearin and Palmitin to one part of olein, human fat which contains less Stearin and relatively more olein, fuses at 25°C. *Olein* ($C_3 H_5 (C_{18} H_{33} O)_3 O_3$) the fluid fat in which, stearin and palmitin are dissolved. Olein solidifies a few degrees above freezing point, and is more soluble than the other fats in ether. *Palmitic Acid* ($C_{16} H_{32} O_2$) and *Stearic Acid* ($C_{18} H_{36} O_2$) are crystalline bodies, chiefly distinguished from each other by their relation to heat, the former fusing at 62°C, the latter at 70°C. Their relations to solvents correspond with those of the fats. Palmitic acid crystallizes from its solution in hot alcohol in bunches of fine needles; stearin in shining plates. *Oleic Acid* ($C_{18} H_{34} O_2$), fluid at ordinary temperatures is decomposed by strong potash, potassic palmitate and acetate being produced.

BILIN.

Bilin (or *Bile crystals*), (as obtained from ox bile) consists of sodic glycocholate ($C_{26} H_{42} Na NO_6$) and taurocholate ($C_{26} H_{44} Na NO_7 S$). These soap-like bodies crystallize from the alcoholic solution of the dry residue of ox bile on the addition of ether. The crystals are very soluble in water and have the peculiar bitter sweetness of bile. When warmed with concentrated sulphuric acid they become resinous and yield after a time a liquid having a green and yellow fluorescence. If after adding a trace of cane-sugar, a liquid containing bilin is mixed with sulphuric acid kept at a temperature between 50°C and 60°C, a purplish violet solution is obtained. Solution of bile crystals is precipitated by the addition of neutral acetate of lead. The heavy precipitate consists of lead glycocholate. By treating its solution in hot alcohol with sulphuretted hydrogen, filtering and adding water to the filtrate, glycocholic acid ($C_{26} H_{43} NO_6$) is obtained as a resinous precipitate. Glycocholic acid is sparingly soluble in water, readily in hot alcohol, from which it crystallizes. When it is boiled with strong hydrochloric acid it is converted into a soluble compound of hydrochloric acid and glycocoll which is very soluble in water, and a resinous product often called *bile-resin* consisting of cholalic acid and dyslysin (see cholalic acid.) When the liquid from which the lead glycocholate has been precipitated is again treated with lead acetate, with the addition of ammonia, a second precipitate is obtained of lead taurocholate. If the washed precipitate is mixed with sodic carbonate, evaporated to dryness and treated with absolute alcohol, a solution is obtained from which sodic taurocholate can be made to crystallize out by the addition of ether. From this solution, taurocholic acid ($C_{26} H_{45} NO_7 S$) may be obtained. It differs from glycocholic acid in being excessively soluble in water, and splitting much more readily into cholalic acid and taurin, than glycocholic acid does into cholalic acid and glycocoll, and lastly in not being crystallizable.

Glycocoll, Glycin or *Gelatin-sugar* ($C_2 H_5 NO_2$ or (as *Amido-acetic acid*) $C_2 H_3 (NH_2) O_2$) is obtained from glycocholic acid by prolonged boiling with strong hydrochloric acid. The firm resin which is formed and consists of cholalic acid and dyslysin (see cholalic acid) having been separated, the remaining liquid yields on evaporation glycocoll-hydrochlorate ($C_2 H_5 NO_2 HCl$). From the aqueous solution of this substance glycocoll is obtained by treating it with hydrate of lead oxide and then decomposing the soluble lead glycocoll, after separating the chloride, with sulphuretted hydrogen. Glycocoll crystallizes in hard rhombohedral crystals which are nearly insoluble in water and insoluble in cold alcohol. The solutions have an acid reaction and sweetish taste. It is called "gelatin-sugar" because, along with tho body Leucin it is a product which is obtained when gelatin is acted on by sulphuric acid. Glycocoll has been obtained synthetically by the action of monochloracetic acid on ammonia. ($C_2 H_3 Cl O_2 + NH_3 = HCl + C_2 H_3 (NH_2) O_2$).

Taurin ($C_2 H_7 NSO_3$) is best obtained from the bile of the dog, in which the whole of the bilin consists of taurocholate. By treating bilin with boiling hydrochloric acid, separating the resin and evaporating the acid liquid, a residue is obtained from which, (after the glycocoll-hydrochlorate has been removed by extracting it with absolute alcohol), taurin can be obtained by dissolving it in water. Taurin is excessively soluble in water, sparingly in cold alcohol. It crystallizes very readily in large 4-or 6-sided shining prisms, each of which ends in 4-sided pyramids. The constitution of taurin can be best understood by remembering how it is obtained synthetically viz., by subjecting ammonic isethionate ($NH_4 C_2 H_5 SO_4$) to a high temperature, in consequence of which it loses the elements of a molecule of water. Neither the origin nor the destiny of Taurin in the organism is known. It was, until lately, supposed that it was represented in the urine by sulphates, and that its amide took part in the constitution of urea, but it has been recently proved experimentally that when dogs are fed with taurin, that body leaves the organism partly as such, but chiefly in the form of Tauro-carbamic acid ($C_3 H_8 N_2 O_4$) a body which is obtained in the laboratory when taurin and potassic cyanate in proportions corresponding to their molecular weights, are dissolved in water and evaporated to the consistence of a syrup.

Cholalic Acid ($C_{24} H_{40} O_5$) is insoluble in water, very soluble in alcohol and ether. It crystallizes from its alcoholic solution in tetrahedra or octahedra, which, at first transparent, soon become opaque on exposure. At high temperatures, it loses H_2O and yields dyslysin ($C_{24} H_{36} O_3$) and undergoes a similar change when boiled with hydrochloric acid. It is contained in decomposed bile as alkaline cholalate and is precipitated therefrom on the addition of acetic acid. From this precipitate it can be extracted by alcohol.

Crystalline Products of Pancreatic Digestion.

The liquid which is obtained when raw fibrin is digested for a few hours or at the proper temperature with pancreatic juice or solution of pancreatin contains, after it has been freed from undissolved residue, besides common albumin alkali-albuminate and peptones, crystalline organic bodies of which the most important are Leucin and Tyrosin. To obtain them, the albumin is first got rid of by slightly acidulating the liquid, boiling and filtering. The filtrate is then reduced to a small bulk by evaporation, and heated with strong alcohol to precipitate the peptone. On again filtering, an alcohol-extract is obtained in which, if left to itself, Leucin and Tyrosin crystallize.

Leucin ($C_6 H_{13} NO_2$) when pure, crystallizes in colourless pearly scales, which sublime in flocks at 170° C like oxide of zinc. In impure solution it forms spheroidal clumps which under the microscope are seen to be made up of round grains each of which consists (like those of chloride of zinc and creatinin) of fine needles radiating from a centre. Tyrosin crystallizes on cooling from its solution in boiling water, in beautiful bunches or stellate groups of long slender needles; it does not sublime when heated.

Leucin is slightly soluble in cold water, Tyrosin almost insoluble. In boiling alcohol Leucin dissolves, Tyrosin remains, so that by means of it the two bodies can be separated from each other. Leucin when heated in a sealed tube with fuming hydriodic acid yields ammonic iodide and caproic acid, and is therefore regarded as amido-caproic acid ($C_6 H_{13} NO_2 + 3HI = C_6 H_{12} O_2 + NH_4 I + 2I$). Tyrosin ($C_9 H_{11} NO_3$) when acted on in the same way yields an acid having the formula $C_9 H_1 O_3$, (Oxyphenyl propionic acid), ammonic iodide and iodine. The physiological destiny of Leucin is unknown. As regards Tyrosin the recent researches of Küssner, have shown that when it is introduced into the circulation, it reappears in the urine as such: it cannot therefore be regarded as a step in the production of urea.

CRYSTALLINE PRODUCTS *of the alcohol-ether extract of* BRAIN.

Neurin or Cholin ($N (C H_3)_3 (C_2 H_5 O) OH$) is a strongly basic, colourless syrupy fluid, which forms crystalline salts with acids. It is soluble in alcohol and water, not in ether. It is readily decomposed by heat, yielding trimethylamine. Glycero-phosphoric acid ($C_3 H_9 PO_6$ or $C_3 H_7 O_3 PO (OH)_2$) the product which is obtained when phosphoric anhydride or glacial phosphoric acid acts on glycerine, is a syrupy body, soluble in water not in alcohol. Taking up H_2O, it splits readily when warmed, into glycerine and phosphoric acid. Along with Neurin and a fatty acid, it is a product of the decomposition of Lecithin, a body which may be regarded as Glycero–phosphoric acid in which 1 atom of hydroxyl is replaced by Neurin, and 2 atoms of H in the radical by 2 atoms of stearyl ($C_{18} H_{35} O$). Lecithin is consequently called Neurin distearyl-glycero-phosphate. Lecithin is an imperfectly crystallizable body which fuses readily, is soluble in ether and swells out in water, like starch, without dissolving. It is obtained by treating the ether alcohol extract of yolk of egg, after first freeing it from fats, with alcoholic solution of platinic chloride. A chloride of platinum and of Lecithin separates, of which the ethereal solution when decomposed by sulphuretted hydrogen, yields Lecithin hydrochlorate as a wax-like mass. The alcoholic solution of this substance when poured into boiling baryta water splits into glycero-phosphate, Neurin and stearate. Bodies of similar constitution in which the radical of stearic acid is replaced by that of palmitic or of oleic acid are also called Lecithins.

Cholesterin ($C_{26} H_{44} O$) is a neutral body which crystallizes readily from ether-extract of powdered gall-stones, (of which it is usually the chief constituent) in rhombic plates which in mass have a mother of pearl lustre. It fuses at 145° C, is insoluble in water, soluble in alcohol, ether, chloroform, &c. When evaporated with nitric acid, the residue on the addition of ammonia acquires a dull red colour. If sulphuric acid is added to its bulk of solution of cholesterin in chloroform, the solution becomes first red then purplish, while the subjacent layer of acid acquires a distinct green fluorescence. A body resembling Cholesterin (Excretin) has been discovered by Marcet in human fæces, to which the formula $C_{20}H_{36}O$ is now attributed.

CRYSTALLINE ORGANIC BODIES OF THE URINE.

Urea or Carbamide ($CO(NH_2)_2$) exists as such in urine—so abundantly in that of the carnivora, that it crystallizes therefrom on evaporation. In human urine it can be crystallized from the alcoholic extract of the dry residue. Urea (U) is excessively soluble in water, soluble in alcohol, insoluble in ether; it is isomeric with ammonic cyanate (NH_4, CNO); takes up water in contact with certain ferments and is transformed into normal ammonic carbonate. ($CO(NH_2)_2 + 2H_2O = CO_3(NH_4)_2$). The same change occurs when U is acted on by alkalies or by strong sulphuric acid, ammonia being given off in the former case, carbonic anhydride in the latter. On the addition of nitric acid to solution of U a snow white precipitate is formed of Urea-nitrate (U, NO_3H) consisting of rhombic plates having a characteristic imbricated arrangement and mother of pearl lustre. Oxalic acid acts similarly, producing Urea-oxalate (U, H_2O_4) but the crystals are not so characteristic. Both bodies are quite insoluble in the acid liquids. An important compound ($2U + Hg(NO_3)_2 + 3HgO$) is obtained as a heavy amorphous white precipitate, when a dilute solution of U is acted upon by dilute solution of mercuric nitrate in excess. This body is insoluble in neutral or slightly acid liquids, but soluble in nitric acid. On adding sodic carbonate to the solution it is precipitated. Hence, if a solution of mercuric nitrate of known strength is added drop by drop to a solution of U acidulated with nitric acid, and the mixture tested from time to time by mixing a drop of it with a drop of sodic carbonate, such mixture will be attended with the formation of an additional white precipitate, so long as there remains any uncombined urea. The moment that all has been used up, the test will indicate the presence of excess of mercuric nitrate in the mixture, by the formation of a precipitate of basic nitrate.

Uric Acid ($C_5H_4N_4O_3$), being soluble in water only in the proportion of one part to 14,000, exists as such in extremely small quantities in urine. Uric acid crystallizes readily in urine to which enough hydrochloric acid has been added to decompose its urates. The most common forms of crystals are the so-called whetstone crystals and the sheaf-like bundles of flattened needles, which (as formed in urine) are always of an amber brown colour. Acid sodic urate ($C_5H_2N_4O_3, HNa$) is always present. In urine of which the urea has undergone transformation into ammonic carbonate, ammonic urate ($C_5H_3N_4O_3, NH_4$) is deposited in needle-shaped crystals which are often in stellate groups. In ordinary urine, when concentrated by evaporation and then cooled, an amorphous deposit falls which consists chiefly of sodic urate. The same body often occurs as a natural subsidence in disease (lateritious sediment). Uric acid and urates reduce cupric oxide and other metallic oxides and salts, just as grape sugar does. When Uric Acid is moistened with nitric acid, the excess of acid gently evaporated, the residue after cooling breathed on, and then held over strong ammonia, a purple red colour is produced, which is due to the formation of murexide; if potash or soda be added instead of ammonia, the colour produced is blue.

Xanthin ($C_5H_4N_4O_2$) the xanthic oxide of Prout, exists in extremely small quantity in urine, in the tissues of certain organs, and as an occasional constituent of calculi. It is very insoluble in water, but soluble in hydrochloric and nitric acids, giving crystallizable compounds with both. When it is heated with fuming nitric acid, and the product evaporated to dryness, a pale yellow patch is left; from this circumstance it derives its name. Xanthin can be prepared artificially by the action of oxidising agents on Hypoxanthin. *Hypoxanthin* ($C_5\,H_4\,N_4\,O$). (Sarkin of Strecker) occurs in the tissue of the spleen and in muscle. It exists in the mother liquor of creatin and can be precipitated from it as an impure compound of argentic nitrate and hypoxanthin by treating the extract with solution of nitrate of silver rendered slightly alkaline by ammonia. Hypoxanthin like xanthin is soluble in nitric and hydrochloric acids yielding crystalline compounds. Heated and evaporated with fuming nitric acid, it gives the same yellow residue as xanthin.

Hippuric Acid ($C_9\,H_9\,NO_3$) occurs in very small proportions (less than 0·1 per cent.) in the human urine or in that of carnivora, but so abundantly as alkaline hippurates in that of herbivora, that on the addition of hydrochloric acid it crystallizes out. It is obtained by boiling the urine of the horse or the cow with milk of lime, filtering, concentrating the filtrate, and adding hydrochloric acid. It crystallizes in four-sided prisms, which have their *arêtes* bevelled off at the ends. Hippuric acid is scarcely soluble in cold water, more readily in hot, but its salts are very soluble. It appears in the urine of man and other non-herbivorous animals, whenever benzoic acid ($C_7\,H_6\,O_2$) enters the organism, Glycocoll being taken up, and water given off. $C_7\,H_6\,O_2 + C_2\,H_3\,(NH_2)\,O_2 = C_9\,H_9\,NO_3 + H_2\,O$. On the other hand, it very readily undergoes decomposition, yielding benzoic acid and glycocoll whenever urine containing it becomes putrid. In the formation of hippuric acid from benzoic acid in the living organism the glycocoll produced in the liver takes part, but it has not yet been proved that the process by which it is normally produced in such large quantity in herbivora, is of the same kind; it has however, been shown that sufficient sources of benzoic acid exist in the food of such animals. As regards the origin of hippuric acid in the carnivora and in man nothing is known. In all animals of which the urine contains much hippuric acid (*e.g.* in the horse), indigo is also present in relatively large quantities. It is no doubt derived from benzoic acid, its production being associated with that of Hippuric acid; Hippuric acid by losing H_2O and CO_2 becomes Indol ($C_9\,H_9\,NO_3 - CO_3\,H_2 = C_8\,H_7\,N$) a body which when injected subcutaneously gives rise to the appearance of Indigo in the urine.

CRYSTALLINE BODIES OF EXTRACTIVE OF FLESH.

Creatin ($C_4\,H_9\,N_3\,O_2$) is obtained by direct crystallization from the water-extract of meat. To prepare it, the extract must be first freed from albumin by boiling, after which the phosphates and sulphates must be precipitated by adding to the strained liquid a mixture of baryta water and baric nitrate. The liquid having been filtered, the filtrate is evaporated over a water bath to a small bulk, when Creatin separates in hard brilliant crystals. Creatin when treated with boiling solution of baryta splits into *Sarkosin* (Methyl-glycocoll) and Urea ($C_4\,H_9\,N_3\,O_2 + H_2\,O = C_3\,H_7\,NO_2 + CO\,(NH_2)_2$). When heated with acids, it loses an atom of water, and is converted into Creatinin ($C_4\,H_7\,N_3\,O$).

Creatinin is an alkaline body which exists in small quantity (about 0·1 per cent.) in urine. It is soluble in cold water, still more so in hot. From its solution in boiling alcohol it crystallizes on cooling. On the addition of syrupy solution of zinc chloride to its aqueous solution, a crystalline precipitate is formed, in which creatinin is combined with zinc-chloride; this is seen under the microscope to consist of characteristic clumps each of which is made up of acicular crystals radiating from a centre.

ALBUMINOUS BODIES.

(Approximate composition in 100 parts:—Carbon 53; Hydrogen 7·5; Nitrogen 15·5; Oxygen 23; Sulphur 1·0).

Albumins. A form of albumin is the chief organic constituent of the colourless transparent part of a raw egg. Another slightly different form is the chief organic constituent of serum. Albumins are soluble in water and their solutions leave on slow evaporation a transparent glass-like residue, which is soluble.

Globulins. Bodies which exist in extremely small quantities, associated with albumins in solution in serum and other similar liquids. Though soluble in such liquids, they are insoluble in water. When a liquid containing a globulin is diluted with water, and treated with CO_2, the globulin is precipitated. Globulins are soluble in ten per cent. solution of common salt, from which they are precipitated by adding salt in substance.

Liquids containing albumins or globulins are called albuminous.

Action of heat on albumins or globulins. When liquids containing albumins or globulins are subjected to a temperature of from 60° C to 70° C, these are precipitated as coagulum. The temperature of coagulation varies, being dependent chiefly on the reaction of the liquid. Similar products are obtained when raw fibrin is boiled, and when the precipitate obtained by adding alcohol to an albuminous liquid is subjected to the prolonged action of that reagent. All albumins or globulins are soluble in 0·2 per cent. solution of HCl as well as in dilute solutions of caustic alkalies. In either case the solution obtained is unaffected by heat and is precipitated when exactly neutralized. The bodies so precipitated are called albuminates—that from the acid solution, acid-albuminate or syntonin, that from the alkaline, alkali-albuminate. Each product is soluble in dilute acid or alkali. The term casein is applied specially to the alkali-albuminate which exists naturally in milk.

Fibrins. Bodies which originate by the "spontaneous coagulation" of certain liquids, to which on this account the term *plasma* is applicable. They are insoluble in water, more or less soluble in solutions of neutral salts and in dilute acids or alkalies. The word fibrin is limited to the product obtained from blood plasma, the word *myosin* to that obtained from muscle. In the spontaneous coagulation of blood plasma, its globulins are partly converted into, or are combined into fibrin.

Peptones.—Bodies which result from the slow change which other albuminous bodies undergo in the process of putrefaction or from the more rapid transformation which is produced by the action of the pancreatic or gastric ferment. They are distinguished chiefly by their diffusibility, and by the absence of the characteristics of other bodies of the group.

Characteristics of Albuminous Liquids. When albumins, globulins or albuminates are present in moderate quantity, they can be recognized by reference to the properties above stated. In very small quantities they can be detected by the following characteristics:—

1. Weak acetic acid containing an albuminous body in solution is precipitated by the addition of solution of potassium ferrocyanide.

2. Solution of KHO containing albuminate assumes a violet colour, when boiled after the addition of a trace of cupric sulphate.

3. On allowing the yellowish liquid which is obtained by boiling an albuminous body in nitric acid to cool, and then adding ammonia, it assumes a bright orange colour.

4. The precipitate which falls when an albuminous liquid is added to "Millon's reagent" becomes brick-red on heating.

ALBUMINOIDS.

Mucin is the precipitate obtained by adding acetic acid to any mucous liquid. It dissolves imperfectly in water, more perfectly if NaCl be present. The solution is tenacious. *Gelatin* is the product of boiling collagen, the chief constituent of the so-called "organic basis" of bone. Gelatin swells in cold water but does not dissolve; its solution in hot water "gelatinizes" on cooling. It is precipitated by tannin and corrosive sublimate, not by acetic acid and potassic ferro-cyanide. *Chondrin* a similar product obtained from cartilage, is distinguished from gelatin by being precipitated by acetic acid, and from mucin by the solubility of the precipitate in sodic sulphate.

COLOURING MATTERS.

Hœmoglobin crystallizes from its solution, in forms which vary according to the animal from which it is derived. The crystals are of the colour of arterial blood, but become dark, without changing their form, when placed *in vacuo* at a low temperature. They then exhibit two colours looking green along the *arêtes*, purplish red elsewhere: on the admission of air or oxygen, the colour is restored.

Hæmoglobin is very soluble in warm water, much less so in cold, but, in this respect, crystals obtained from different animals differ: thus, the hæmoglobin of the rat or guinea-pig is less soluble than that of man and is much more prone to crystallize.

Hæmoglobin contains $\frac{1}{238}$ of its weight of iron; consequently its atomic weight cannot be less than 13,328. It is known experimentally that a gramme of hæmoglobin which has been exposed to air, yields to the vacuum 0·00239 gramme of oxygen (= 1·671 cubic cent. at 0° C and 760 mm.) As a gramme of Hæmoglobin contains 0·0043 gramme of iron, the weight of oxygen which a gramme of hæmoglobin is capable of fixing, is to the weight of iron it contains, as 239 to 430. Solution of hæmoglobin exhibits before the spectroscope characteristic absorption bands. Very dilute solution shows one band to the blue side of the D line; if the solution is stronger, a second band appears to the red side of the E line; by still more concentrated liquids, the blue and violet rays are entirely absorbed, while the two bands become confluent.

When blood is allowed to stand at ordinary temperatures, its hæmoglobin is soon decomposed, yielding hæmatin, albuminates and other products. The same thing happens much more rapidly when solution of hæmoglobin is acted on by alkalies. In presence of weak acids hæmoglobin yields hæmatoin (so-called "acid hæmatin") and acid albuminate.

Hæmatin ($C_{68} H_{70} N_8 Fe_2 O_{10}$) is obtained when weak potash solution acts on blood or solution of hæmatin *with access of air*. On neutralizing, solid hæmatin is precipitated. It is insoluble in water, alcohol and ether, and uncrystallizable.

The absorption spectrum of hæmatin presents a broad band to the red side of the D line. After reduction by alkaline sulphides it shows two characteristic bands, one in the yellow, the other in the green part of the spectrum. When dried blood is warmed with glacial acetic acid, it yields crystals of *hæmin* (hæmatin + 2 HCl).

Solution of hæmoglobin associates nitric oxide and carbonic oxide in the same volume as oxygen. When oxygenated solution of hæmoglobin or of blood is acted on by carbonic oxide, its associated oxygen is replaced by that gas. The solution acquires a colour which closely resembles that of arterial blood, but is not affected by reducing agents.

Bilirubin (Cholepyrrhin $C_{16} H_{18} N_2 O_3$) can be obtained directly from human bile, or that of the dog by shaking it with chloroform. On separating the solution thus obtained from the bile and then distilling off the chloroform, a pitchy residue is left, which, after it has been exhausted by alcohol is found to contain crystals of bilirubin. The alcohol contains cholesterin and a brown colouring matter which has been called bilifuscin. Bilirubin is a principal constituent of biliary calculi; powdered gall stone which has been extracted successively with hot water, alcohol, ether, and hydrochloric acid, yields, when treated with chloroform, a green solution, from which bilirubin is precipitated on the addition of alcohol, or crystallizes on evaporation in red needles. It is insoluble in water, nearly insoluble in boiling alcohol and in ether, more soluble in bisulphuret of carbon, and most of all in chloroform. Its solution shows no absorption bands. It further dissolves readily in potash or soda, and when the alkaline solution is exposed to air, it gradually becomes green, and gives, when treated with hydrochloric acid, a green precipitate (*biliverdin*), which is insoluble in chloroform but soluble in alcohol. Bilirubin, in dilute alkaline solution when acted on by sodium-amalgam, yields Maly's *Hydro-bilirubin*, a red body insoluble in water, of which the solution in absolute alcohol shows before the spectroscope a broad absorption band, between E and F. It is supposed by its discoverer to be identical with the colouring matter of fæces (*stercobilin*) and with the *urobilin* of Jaffe, from both of which, however, it differs in important respects. The physiological origin and destiny of the colouring matter of the bile is known. It has been shown experimentally that when crystalline hæmoglobin in solution is injected into the circulation, the rate at which colouring matter is secreted by the liver, increases enormously, and that bile pigment appears in the urine. In the intestines most of the Bilirubin secreted is converted into stercobilin and discharged, but the chemical relations between it and the excreted colouring matters are as yet uncertain. Liquids which contain bilirubin change colour on the addition of nitric acid containing a trace of nitrous acid: at first green, the colour passes through blue, violet and red, finally fading into yellow. During the change the liquid shows when examined spectroscopically three absorption bands, of which the first and second are near the line D, and are due to the blue colour (*cholecyanin*), the third is between b and F and is referable to the red colour (*choletelin*) *i.e.* in the same position as the absorption band of urobilin.

The yellow colouring matter of the urine is obtained by first treating the liquid with milk of lime, and allowing it to stand. After separation of the deposit, the clear filtrate is precipitated by solution of plumbic acetate to which a little ammonia has been added. The lead precipitate having been treated with just sufficient sulphuric acid to decompose it, yields a yellow solution, which owes its colour to a body to which the name urochrome was given by Thudichum, and is now commonly used. This body is soluble in water, insoluble in alcohol. Its solution exhibits no absorption bands before the spectroscope. On boiling it for some hours with sulphuric acid, various brown or black substances are formed, the most characteristic of which (called *uromelanine*) is soluble in ammonia, and is re-precipitated on neutralizing the solution with sulphuric acid. Of the chemical relations of urochrome little is known.

Indigo forming substance. Urine (particularly that of the horse) when mixed with half its volume of strong hydrochloric acid, becomes dark, and after some hours, deposits a scum or sediment wihich contains indigo-blue ($C_8 H_5 NO$). If this scum is collected on a filter and treated with ammonia, a blackish substance with which it is mixed is dissolved and removed. If after washing the filter with cold alcohol (which dissolves out a red colour) the filter and residue are boiled in the same solvent, a beautiful blue solution is obtained, which on cooling deposits flocks of indigo-blue. As to the probable physiological origin of indigo in the urine see hippuric acid.

INORGANIC SALTS.

The following soluble salts exist in the living blood or juices, as such :

Sodic chloride; hydro-sodic bicarbonate ($CO_2\ H\ Na$); *sodic carbonate* ($CO_3\ Na_2$); *sodic phosphate* ($PO_4\ Na_2\ H$); *sodic sulphate;* corresponding *potassic* salts.

The urine contains the following soluble salts: *acid sodic phosphate* ($PO_4\ Na\ H_2$); *sodic phosphate; acid calcic phosphate* ($(PO_4)_2\ CaH_4$); *acid magnesic phosphate; alkaline chlorides* and *sulphates.*

In the insoluble part of the alvine excreta the following insoluble salts exist : *calcic phosphate* ($(PO_4)_2\ Ca_3$); *magnesic phosphate* and *ammonio-magnesic phosphate* ($PO_4\ Mg\ NH_4\ (H_2\ O)_6$).

GASES.

Carbonic anhydride, oxygen and nitrogen are yielded to the vacuum by the blood and juices. The intestinal contents also contain hydrogen, marsh gas and a trace of sulphuretted hydrogen.

PART I.

CHEMICAL PROCESSES OF ANIMAL LIFE.

ANIMAL life, as observed in man and the higher animals, is an aggregate of chemical processes for which food and oxygen afford materials, the products being heat, muscular action, carbonic anhydride, water and ammonia. Food essentially consists of albuminous bodies, carbonic hydrates and fat all of which undergo chemical disintegration in the animal body in addition to water and certain inorganic salts. The fats and carbonic hydrates owe their chief importance to their being the sources from which the organism derives the material for muscular action and the production of heat.

Vegetable life is also a chemical process. Green plants build up their tissues out of carbonic anhydride, ammonia and certain inorganic salts. Colourless plants do not dissociate carbonic anhydride, but derive their carbon entirely from the soil on which they grow. The most important constituents of the tissues of plants are albuminous bodies, and carbonic hydrates; for these exist in all plants. Tho characteristic property of a plant is its power of forming its tissues out of inorganic materials.

The term *protoplasm* is used to denote the apparently but not really homogeneous substance out of which the active parts of the tissues of plants and animals are formed. It consists chiefly of albuminous bodies, and exhibits in itself all the essential phenomena of life. For in it, not only the general actions which belong to the organism as a whole, but the specific actions of particular parts, such as those of muscle, nerve and gland, have their seat.

FOOD.

Flesh owes its nutritive value to its albuminous and collagenous constituents, its fat and its salts. Lean meat (beef) contains about 25 per cent. of solids, of which 18 per cent. is albumin, and yields about half a percentage of gelatin to boiling water. Flesh of young animals (veal) yields 5 to 10 times as much. The interstitial fat of meat varies in quantity from 4 to 15 per cent.

Meat yields to warm water at 60°C about 3 per cent. of albuminous material and nearly as much extractive. On boiling the aqueous extract, the albumin coagulates (as scum), but when the boiling is long continued some of it redissolves (Mulder). Consequently the quantity of albuminous material contained in *bouillon,* always small, varies according to the mode of preparation. It may be increased by the addition of a trace of hydrochloric acid to the water used. Bouillon, beef tea and other similar products owe their value, partly to the gelatin, but chiefly to the *salts* and extractive which they contain.

Meat when roasted, retains its juice, which, from the comparatively low temperature of the internal parts (indicated by the colour) does not coagulate. The tenderness which meat acquires by keeping is due to conversion of some of its myosin into albuminate.

Cooking is necessary, not only as preparatory to digestion, but as destructive of parasites and of morbid and septic products.

Milk.—All of the constituents of milk are of great nutritive value. *Cream* consists chiefly of casein and butter; *Butter milk* of sugar, casein and salts; *Whey* of sugar and salts; *Cheese* of casein with variable quantities of butter, and of the products of decomposition of both. Human milk contains less than 3 per cent. of casein, between 3 and 4 per cent. of butter, and from 4 to 5 per cent. of sugar. *Colostrum* differs from it chiefly in containing about 2 per cent. of serum albumin. Cows' milk is nearly twice as rich in casein but contains no more sugar: consequently, when it is diluted, as a substitute for human milk, milk sugar (which as crystallized from whey always contains calcic and potassic phosphates) must be added.

Eggs.—Eggs contain about 73 per cent. of water, 15 of albumen and 12 of fat.

Cereals, Pulses and other Vegetable Foods.—*Wheat flour* derives its alimentary value from its large per centage of albuminous bodies and starch, but chiefly from its containing gluten, and its consequent adaptedness for bread-making. In the fermentation of dough, grape-sugar splits into alcohol and carbonic acid under the influence of the yeast plant. By this means the dough is raised. In baking, the dough is subjected to a very high temperature (150° C to 200° C). Most of the starch becomes soluble, and much of it is converted, especially in the crust, into dextrine. Notwithstanding the destruction of sugar in fermentation, a loaf weighs about a quarter more than the flour used to make it. *Rye flour,* also used for bread making, yields a less perfect product. It contains more cellulose and less albuminous substances. *Barley* is as rich as wheat in albuminous bodies, but neither barley nor *oat* flour can be used for bread-making. Barley owes its importance to its being a source of diastase and grape sugar. *Maize,* although poor in albuminous bodies is rich in starch, but in both these respects, it is exceeded by *rice.* Rye and maize are severally liable to a parasitic disease which renders the grain morbific. The *Pulses* owe their value to the legumin they contain, and to their large per centage of albuminous compounds. *Potato* contains 75 per cent. of water. In the dry state it contains about 8 per cent. of albuminous bodies and 70 per cent. of starch. Its cellulose becomes gelatinous by boiling and is thus soluble in the digestive liquids. *Fruits* and *succulent vegetables* owe their nutritive value to the sugar they contain. Their percentage of albuminous material is very small.

TABLE I.

Percentages of albuminous substances, fat, carbonic hydrates and of water in certain Vegetable Foods. (Wolff).

	Albm. Subst.	Fat.	Carbo-hydrates.	Water.
Wheat Meal ………… ..	11·8	1·2	73·6	12·6
Rye Meal …… ………..	11·0	1·6	71·9	14·0
Barley Meal ……………	10·0	2·0	73·5	12·5
Oat Meal ………………	14·5	6·0	63·4	14·0
Maize Meal ……………	11 0	7·0	67·6	13·5
Rice Meal ………………	7·5	0·3	78·1	13·5
Buck-wheat Meal ……	9·0	1·5	76·5	13·0
Bean Meal………………	24·5	2·0	55·6	14·5

Inorganic Salts of Food. Beef yields when dry, about 4 per cent. of ash, of which about half is reckoned as potash. The most important potassic salts are phosphate and chloride. The proportion of sodium salts is very small. In boiling meat, nearly the whole of its alkaline salts pass into the bouillon. Wheat flour contains about 2 per cent. of ash in which potash is by far the most important base. About half the weight of the ash is reckoned as phosphoric anhydride.—The constitution of the ash of potatoes and other juicy vegetables is similar, but the yield of phosphoric acid is much less. The percentage of potash is about five times as great as that of all the other bases together. Milk yields about 2·5 per thousand of ash, of which about 1 per thousand is reckoned as potash, 0·25 as soda, and about 0·4 as lime.

In an adequate diet comprising 250 grammes of meat and 400 grammes of bread, the former would yield 1·5 grammes of potash, the latter 1·6. An adequate diet of milk (2½ litres) would yield about 3 grammes.

DIGESTION,

including the physiology of the Liver and Pancreas.

Muscular movements accessory to Digestion.

(This subject is further treated of in Part III.) The chief muscles of mastication are, the masseter, internal pterygoid, temporal, and external pterygoid. In deglutition all of the muscles of the tongue, of the soft palate and of the pharynx take part. During the first part of the act of deglutition, which is voluntary, the morsel is pushed back by the tongue, through the anterior arch into the pharynx. During the second part, which is reflex, it is pushed downwards by the constrictors, which contract in the order of their position, the pharynx being closed towards the mouth by the anterior arch, towards the nares by the velum, towards the larynx by the back of the tongue and the epiglottis.

The œsophagus consists of a mucous tube contained in a muscular tube, to the inside of which it is very loosely attached. The former being at least as large as the latter is consequently folded longitudinally. The œsophagus contracts peristaltically; each contraction begins at the upper end.

The movements of the stomach during digestion are of the same nature; but as the pylorus is closed the contents as they reach it flow back along tho smaller curvature towards the cardia.

The peristaltic movement of the intestine resembles that of the œsophagus, but is less regular. It is immediately dependent on the intrinsic nervous system of the intestinal wall, but is controlled by cerebro-spinal centres. In defæcation, whatever fæcal masses are already in the rectum and and sigmoid flexure are expelled. In this act the diaphragm, the muscles of the abdominal wall, and the levator ani contract simultaneously, while the sphincter externus (a muscle of which the action is partly voluntary, partly reflex) relaxes.

Digestion in the Mouth.

Saliva is a mixture of the secretions of the salivary glands. Submaxillary saliva is slightly alkaline and tenacious. It contains globulin, albumin and mucin. It also contains a diastatic ferment. Parotid saliva contains little or no mucin, and is consequently free from tenacity. The salivary glands normally exercise their function only in answer to stimulation of a sensory nerve. The effect of stimulation is conveyed to the submaxillary gland by the chorda tympani, to the parotid by the smaller superficial petrosal nerve. Normally the stimulus is either gustatory or associated with the sense of taste. Experimentally the same effect can be produced by electrical stimulation either of the lingual or of the proper nerve of the gland. In either case the act of secretion is attended with increased circulation through the gland. This is not the cause of the secretion. The mechanical force of the secretion is sufficient to produce a pressure in the duct, (if it is occluded) higher than that of the arterial system.

Saliva owes its value in digestion, chiefly to its diastatic ferment, but it is also of use as a solvent and lubricant.

Digestion in the Stomach.

Gastric juice is a colourless transparent liquid of very low specific gravity. It contains neither albumin nor mucin, and may be regarded as a solution of pepsin, hydrochloric acid, chloride of sodium and other salts. It is secreted by the peptic cells of the glands of which the mucous membrane chiefly consists. The secretion takes place in answer to mechanical or chemical stimulation of the mucous surface; the act is attended with increased circulation of blood in the mucous membrane.

The process of gastric digestion consists in the transformation of the albuminous bodies of the food into peptones under the combined influence of pepsin and of a free acid. In the dog, the gastric juice can be proved to contain free hydrochloric acid, for the quantity of chlorine in it is more than sufficient to combine with all the metals present. Lactic acid is present in chyme whenever carbo-hydrates are being digested. It has been found that hydrochloric acid can be replaced by phosphoric acid, as well as by acetic and other acids of the same series.

Pepsin, although resembling the albuminous bodies in chemical composition, exhibits none of their distinctive characters. It exists in gastric juice in a state of imperfect solution so that it can be removed from it by mechanical means; on this fact Brücke's method of preparing pure pepsin is founded. It is capable of taking part in the digestion of albuminous substances, even in the smallest quantity, provided that the liquid is not too dilute, and that it does not contain too large a proportion of the product of digestion—peptone. In the process, the pepsin neither increases, diminishes nor undergoes any loss of activity.

The substance commercially known as pepsin consists of dried gastric mucous membrane, and hydrochloric acid. A solution of pepsin which possesses its digestive properties is obtained by extracting fresh mucous membrane with glycerine.

Peptone is identical in chemical composition with albumin, but is distinguished from it by being hygroscopic and diffusible. (For its reactions see Stœchiology).

In animals that die during digestion, the stomach digests itself after death. During life such digestion is prevented by the alkalinity of the tissues. Chyme, as it leaves the stomach, contains remains of animal and vegetable structure, unaltered starch grains, fat particles, and (after milk diet) curd particles. It does not normally contain bile. It yields a mixture of gases in which there is much less oxygen than in common air, and a larger proportion of CO_2.

Intestinal Digestion.

The secretion of the intestinal mucous membrane is alkaline, effervesces with acids, and probably contains a digestive ferment.

Pancreatic juice is an alkaline liquid resembling saliva. It is, however, of greater density and probably contains no globulin. It owes its activity to two ferments,—a diastatic and a peptic—both of which are contained in the precipitate which is thrown down when pancreatic juice is treated with alcohol, and can be extracted from it by glycerin. The peptic ferment can be separated mechanically from the pancreatic juice, and is the first to be precipitated by alcohol. It digests fibrin and other albuminous bodies in alkaline liquids, when peptones, leucin, tyrosin and other products are formed. Pancreatic juice emulsionizes and decomposes neutral fats. It has lately been proved (Heidenhain) that the peptic ferment does not exist in the tissue of the living pancreas.

Secretion of Bile.

Human bile contains 17 per cent. of solids of which 10 per cent. is bilin, 4 per cent. fat, 2 per cent. mucus and colouring matter, 1 per cent. salts. Of these, bilin and colouring matter are the most characteristic. Bilin consists of sodium salts of bile acids. It is obtained by precipitation of the alcohol extract of the solids (dry residue) of bile with ether, and yields the two bile acids when decomposed by sulphuric acid. In bile which has been long exposed, or has been subjected to the action of acids or alkalies with heat, the bilin is transformed into cholic acid and two amide compounds, taurin, and glycin or gelatin-sugar. Cholic acid yields dyslysin under the influence of septic ferments. With sugar and sulphuric acid it exhibits "Pettenkofer's reaction."—Cholesterin is the chief constituent of gall stones; it crystallizes readily from its solution, in rhombic plates. It occurs in many pathological products. In the bilo, as in the tissue of the nervous system and in the blood corpuscles, it is associated with lecithin.

Of the colouring matters bilirubin is the most important constituent. It is nearly allied to hæmatin in constitution, and is no doubt derived from it. It is perhaps identical with hæmatoidin.

In intestinal digestion the bile is antiseptic. It also promotes the absorption of fat. Bilin (or rather the products of its decomposition) is absorbed. Of the colouring matter, most is discharged in an altered form (Stercobilin).

Nothing is as yet known as to the influence of the nervous system on the secretion of bile.

Glycogen.

Glycogen, or animal starch always exists in greater or less quantity in the living substance of the liver. It is easily prepared by extracting the liver of an animal just killed, with boiling water, and precipitating the filtered extract with alcohol. The percentage of glycogen in the liver increases after each period of digestion. It originates partly from the carbonic hydrates of the food, partly by disintegration of albuminous substance (probably peptones). In glycosuria the grape-sugar which exists in the blood and is discharged by the kidneys, is derived from the glocogen of the liver. It is not known how much glycogen is normally converted into sugar, and how much is oxidized otherwise.

The secretion of sugar is augmented by any cause which excites the afferent fibres of the vagi, or increases the circulation of arterial blood in the liver.

Intestinal Absorption.

In intestinal absorption the dissolved constituents are absorbed by the blood stream, the particulate by the lacteals.

Of the albuminous compounds alkali albuminate is absorbed much more readily than coagulable albumin. The latter can only be absorbed in presence of diffusible neutral salts, particularly chloride of sodium. These bodies behave according to their "osmotic equivalents."

Fæces consist of insoluble residues of food and bile, and of insoluble salts, particularly calcic, magnesic, and ammonio-magnesic phosphates. They yield certain gases, viz., CO_2, marsh gas and a trace of sulphuretted hydrogen. In human excrement a crystalline body called excretin occurs.

Blood and Lymph.

Blood is an opaque fluid mass, each cubic millimeter of which contains more than 4,000,000 corpuscles floating in an alkaline liquid. Of these about one in 400 are colourless. In circulating blood the corpuscles are equally distributed. Out of the living body, blood coagulates, that is, separates into clot and serum; or, if coagulation is prevented by a freezing temperature, into corpuscles and plasma. If blood is agitated before coagulation, the fibrin is collected on the agitating surfaces, and thus separated from the cruor. The coagulum varies in character according to the number of corpuscles, the time occupied, and the form of the recipient. It consists essentially in the concretion of the plasma into a felt-work of transparent fibres, each of which is scarcely a micromillimeter in width, and shortens immediately after it is formed. In the circulating blood coagulation is prevented by the influence upon it of the living tissues, with which it is in relation. If blood is received into non-contaminated vessels, coagulation is delayed or prevented. It is not dependent on the access or escape of any gas or vapour. It is indefinitely deferred at 0° C., most accelerated at 40° C. By subsidence at about 6° C. blood separates into plasma and corpuscles. The plasma constitutes about two thirds by weight of the blood. It contains three albuminous substances, viz.; (1) common albumin (of which the amount equals five or six per cent. of the blood weight); (2) a little alkali albumin; and (3) the substance which becomes fibrin.

Blood albumin or Serin closely resembles egg-albumin, being distinguished from it chiefly by its greater solubility in concentrated hydrochloric acid. It is obtained in solution free from the other constituents, by precipitating serum with basic lead acetate, and decomposing the precipitate with CO_2. The solution when freed from lead by sulphuretted hydrogen, yields on evaporation soluble serin. Plasma coagulates at ordinary temperatures, becoming gelatinous if diluted, yielding a firm clot of fibrin if concentrated. In other words, it contains when in the state in which it exists in circulating blood, in addition to the constituents of serum, a substance (globulin or coagulin) which by concretion becomes fibrin. Of this there are two forms, viz., fibrino-plastin and fibrinogen. Both are precipitated, after previous dilution of the liquid with water, by CO_2, and by neutralizing with acetic acid. In undiluted plasma, the globulins can be separated by the addition of common salt in fine powder. The two bodies are distinguished from each other by the conditions under which they are precipitated by CO_2 and the form of the precipitate. Serum contains fibrinoplastin, but no fibrinogen. Hydrocele fluid contains fibrinogen but no fibrinoplastin. All coagulable liquids contain both forms, but in such liquids coagulation is delayed by the presence of neutral salts, accelerated by dilution. Blood after it has been withdrawn from the circulation contains a ferment, which when added to a coagulable liquid in the smallest quantity determines coagulation.

The Plasma of blood contains about 0·5 per cent. of the total blood-weight of soluble salts, of which between 0·3 and 0·4 is sodic chloride, and about 0·1 sodic phosphate, the remainder consisting chiefly of sodic carbonates. The insoluble calcic and magnesic phosphates, of which plasma contains about 0·04 per cent. of the blood-weight, are held in solution by combination with albumin.

Plasma contains oxygen and nitrogen in about the proportion in which these gases are severally found in water. It contains somewhat more free CO_2 than the serum would absorb if it were so much water.

Blood disks.—The coloured blood corpuscles consist of stroma and hæmoglobin. They constitute about a third of the weight of the blood, and contain 42 per cent. of solids, and 36 per cent. of hæmoglobin. The stroma is made up for the most part of substances soluble in ether, viz., lecithin and cholesterin, and an albuminous body having the properties of globulin. The blood-corpuscles also contain inorganic salts, which differ from those of the plasma, in the substitution of potassic chloride and phosphate for the corresponding compounds of sodium.

In normal blood, hæmoglobin exists only in the corpuscles, but in certain diseased states it is dissolved in the plasma and is then crystallizable: the nature of the change it undergoes is not known. A similar change is produced artificially by repeated freezing and thawing, by subjecting blood to a temperature of 60° C. or by the action of ether or chloroform. The property which the blood possesses of absorbing oxygen from the inspired air and of giving it up to the living tissues, with which it is brought into contact in the circulation, is due to its hæmoglobin.

The quantity of oxygen yielded to the barometer vacuum by any quantity of aerated defibrinated blood is equal to the quantity associated by the hæmoglobin contained in the blood, *plus* the quantity absorbed by the plasma; (hence for every 5 centigrammes of iron, 20 cubic centimeters of oxygen at 0° and 760 m.m.) In ordinary arterial blood the yield of oxygen is a little less. Arterial blood at 40° yields about 40 per cent. of its volume of CO_2 as measured at 0° and 760 m.m. The alkaline carbonates are decomposed in the vacuum without the addition of an acid.

The human body contains about $\frac{1}{14}$ of its weight of blood.

In the examination of blood for chemical purposes it is chiefly important to determine the percentage of hæmoglobin and the alkaline reaction.

Arterial blood becomes venous by contact with living protoplasm. Venous blood is distinguished from arterial by its crimson colour, its slight dichroism, the less proportion of oxygen which is associated with its hæmoglobin, its large proportion of combined CO_2, its less proneness to coagulation, and by containing fewer blood corpuscles. Venous blood differs somewhat in composition according to its source. As compared with ordinary venous blood that of the hepatic vein contains less albumin, more extractives (*e.g.* urea and grape-sugar) and less hæmoglobin. That of the splenic vein contains about ten times the normal relative number of colourless corpuscles, and fewer blood disks. These differences indicate that in the spleen the coloured blood corpuscles are disintegrated, and that large numbers of colourless corpuscles are formed. In these functions the spleen is associated with other structures, particularly the medulla of bone. Splenic blood is further distinguished by the presence of certain crystalline immediate principles derived from the spleen pulp, *e.g.* hypoxanthin and uric acid.

Lymph.

Lymph or tissue juice resembles blood in being coagulable and in containing colourless corpuscles. It differs from it in being of lower specific gravity, in the tardiness with which it coagulates, in the absence of hæmoglobin, in the presence of excess of fibrinogen in its serum, and in its containing relatively to its weight more urea and other extractives, more sodic carbonates, and much more CO_2. Its corpuscles are derived partly from the tissues, partly from the lymphatic glands. They are characterized by the presence in the protoplasm of which they consist, of a body resembling myosin, and of a body in their nuclei resembling mucin. They have been also found to contain glycogen.

Chyle differs from lymph chiefly in respect of the considerable proportion of fat (about 1 per cent.) which is present in it.

CHEMICAL PROCESS OF RESPIRATION.

In respiration each quantity of air respired undergoes the following changes:—Its oxygen is diminished by about a quarter, viz., from 21 per cent. to 6 per cent. Its CO_2 is increased a hundred-fold, viz., from about 0·04 per cent. to over 4 per cent. It becomes saturated with moisture. It acquires nearly the temperature of the body. It becomes more or less charged with organic impurity, acquiring thereby a peculiar smell. Its volume is diminished by $\frac{1}{250}$ or thereabouts. Its weight is increased in proportion to the weight of CO_2 discharged.

The loss of weight of the body when no food is taken and no liquid or solid excreta are discharged, is called the "insensible loss." The insensible loss is made up of the sum of the CO_2 and water discharged, *minus* the weight of oxygen absorbed. In man it amounts to about 27 grammes per hour.

Of the total hourly discharge of CO_2 less than half per cent. is cutaneous. The hourly discharge of CO_2 by weight by an adult male when at rest, is about 32 grammes, the weight of oxygen absorbed in the same time being 25 grammes. The hourly discharge of water vapour is about 20 grammes.

Weight of 1 Litre of CO_2 (at 0° C. and 760 m.m.) = 1·9712 grammes.
,, ,, O ,, ,, = 1·4336 ,,
So that 32 grms. of CO_2 = 16·2 Litres
and 25 ,, ,, O = 17·5 ,,

$$\text{Hence the Quotient } \frac{CO_2}{O} = \frac{23{\cdot}25}{25{\cdot}0} = \frac{93}{100} = \frac{\text{weight of O in. } CO_2}{\text{weight of O}}$$

In the investigation of the chemical process of respiration in man or the lower animals, three quantities are to be determined, viz., the discharge of CO_2, the absorption of oxygen and the discharge of water. In the most complete methods (*e.g.* that of Régnault and Reiset) all three are determined. In Pettenkofer's method, the total CO_2-discharge only is determined; but the method has the advantage of being applicable to large animals and to man.

The percentage of CO_2 is dependent on the length of time that the expired air has remained in the respiratory cavity. (It can be increased by voluntary retention to 7·5 per cent.) Consequently as the frequency of respiration increases the percentage diminishes though the total discharge increases.

Example :—

Frequency	6	24	48
Cubic centims of CO_2 per minute	171	396	696
,, ,, per respiration	28·5	16·5	14·5

(Vierordt).

The frequency remaining the same, the CO_2 increases with the amplitude of the respirations.

Example :—

Frequency—12 respirations per minute.

Amplitude.	CO_2 per min. (c. c.)	Percentage.
3 Litres	162	5·4
6 ,,	240	4·5
12 ,,	480	4·0
24 ,,	816	3·4

(Vierordt).

In the compressed air chamber the respirations become more ample and the CO_2 discharge increases.

The influence of increase and of diminution of the atmospheric temperature varies according to its effect on the temperature of the body. If the latter is increased or diminished, the discharge of CO_2 is increased.

The influence of food on the rate of discharge of CO_2 is direct and immediate. The increase after each meal, which may amount to 20 per cent, reaches its maximum in about 2 hours. The effect is most marked when the diet consists largely of carbonic hydrates.

Exchange of gases.—If a liquid is exposed to a gas, the former absorbs the latter until equilibrium is established. As soon as this is the case the tension of the gas in the liquid is said to be equal to its tension outside of it. If a liquid is exposed to a gaseous mixture, the absorption of each gas takes place as if there were no other. If a very small volume of a gaseous mixture is exposed to an indefinitely large volume of a liquid containing gases, the latter will be absorbed from, or given off into the former until the tension of each gas in the mixture is equal to its tension in the liquid. When this experiment is made in the circulating blood, the oxygen of the mixture (atmospheric air) diminishes, for the tension of oxygen in such blood scarcely exceeds 20 millimeters ($= \frac{1}{35}$ atmosphere), while the CO_2 increases until its tension amounts to about 30 millimeters.

Respiration can be maintained without much difficulty in an atmosphere which contains much less than the normal proportion of oxygen, so much so that an animal supplied with a limited quantity of air, continues to breathe it until it has used all but a fraction of the oxygen it contains.

The tension of carbonic acid in the air contained in the air cells, is as great or greater than that of venous blood: consequently no discharge of CO_2 would occur unless some agency existed by which the CO_2 tension is rendered greater in the pulmonary capillaries than anywhere else in the circulation. That this is actually the case is indicated by the facts (1) that sodic carbonate is relatively more abundant in venous than in arterial blood; and (2) that the addition of oxygenated hæmoglobin to serum in vacuo decomposes its carbonates setting free CO_2, so that venous blood yields more CO_2 to oxygen than to the barometer vacuum. Consequently the discharge of CO_2 in pulmonary respiration is directly promoted by the absorption of oxygen.

The process by which the circulating blood gives oxygen to the living protoplasm with which it comes into relation in the capillary blood-vessels, and receives CO_2, is often called "internal respiration." The existence of such an exchange of gases in the tissues is proved by the observation that venous blood differs in the proportion of oxygen and CO_2 which it contains, according to the tissue through which it has circulated.

The separation of CO_2 by protoplasm, and the absorption of oxygen are distinct and independent processes and do not go on *pari passu*. The former is variable; its variations are dependent on the functional activity of the tissue; the latter is constant and is associated with restitution. The independence of the two processes is proved (1) as regards muscular tissue by the observation, that muscle which has been entirely deprived of oxygen, can be thrown into functional activity (*i.e.* contraction) without receiving any supply of air or oxygen, and that in contracting it gives off CO_2 (Hermann) and (2) as regards the entire organism, by the observation that a frog if kept at a low temperature continues to discharge CO_2 at nearly the normal rate, in an atmosphere of pure nitrogen (Pflüger).

PRODUCTION OF HEAT.

Animal heat, like mechanical work, is the result of the chemical process of the conversion of food into water, CO_2, urea, and other excreted products.

An approach to an experimental proof of this is obtained by investigating (1) the quantity of heat produced by a man or an animal in a given time; (2) the quantity and quality of the food consumed; (3) the physiological heat-value of each kind of food.

Of these investigations (1) is accomplished calorimetrically; (2) by the ordinary methods of chemical analysis; (3) by determining the quantity of heat produced by each substance used as food when completely burnt. As regards those substances which undergo complete disintegration in the animal body, the result so obtained is the physiological heat-value of the substance, but as regards substances containing nitrogen the result must be corrected by deducting from it the heat produced by the combustion of the equivalent weight of urea. Thus, albumin, which by complete combustion yields 4998 units of heat, has a physiological heat-value of only 4263 units. The results so obtained, although only approximately correct in application are correct in principle; for however various may be the chemical processes of animal life their value as regards the quantities of heat and work produced must be estimated by the end-products of the whole process. (*See* exchange of material.

Of the heat produced in the body it is estimated that about

73 per cent is discharged by radiation and evaporation from the surface; 20 per cent by the lungs and excreta, while 7 per cent is represented by mechanical work. Accordingly, (1) the loss of heat varies with the velocity of the circulation; (2) during the performance of mechanical work the quantity of heat lost by the body is less as compared with the CO_2 discharged than during rest.

The mean temperature of the body is remarkably constant, but is higher in the central than in the superficial parts. The uniformity of temperature is dependent on the constant equilibrium of the two processes by which severally heat is produced and discharged.

Production and Discharge of Urine.

The average daily discharge of urine of an adult male on full diet is 1500 grammes, containing about 36 grammes of urea; 0·7 gramme of uric acid; 16 grammes of sodic chloride; and about 6 grammes of other inorganic salts; besides colouring matter and other organic constituents. Hence urine contains about 4·0 per cent. of solids, including 2·4 per cent. of urea. Its acidity is equal to that of a 0·2 per cent. of solution of oxalic acid.

The salts of the urine are, common salt, potassic chloride, sodic, calcic, and magnesic phosphates; and sodic and potassic sulphates. The discharge of sodic chloride varies with the store of chlorine in the body. It is markedly diminished by abnormal transudation of blood plasma.

When urine becomes alkaline the earthy phosphates are precipitated. The discharge of alkaline phosphates varies with the quantity stored in the blood plasma; that of earthy phosphates with the disintegration of albuminous substances. All the sulphuric acid of the urine is the product of disintegration. If carbonates exist in the urine they are derived from the oxidation of vegetable acids used as food.

Urea or carbamide crystallizes in the alcoholic extract of the evaporation residue of urine. It is very soluble in water, soluble in hot alcohol, less soluble in cold alcohol. It forms insoluble compounds with nitric acid and oxalic acid, and a white insoluble precipitate with mercuric nitrate. In the so-called alkaline fermentation of urine, urea is converted into normal ammonic carbonate, while triple phosphate (ammonio-magnesic phosphate) is deposited.

Urine if uncontaminated may be kept for an indefinite period without any change, excepting that its acidity and colour increase slightly soon after it is passed (acid fermentation); if contaminated it becomes ammoniacal.

Urea is normally derived from the disintegration of albuminous and albuminoid substances of food or tissue, but it may originate from other sources. It is not formed exclusively in the kidneys but also in other organs and tissues, as *e.g.* in the liver.

The rate at which nitrogen is discharged from the organism is estimated by that of urea. Thus we learn that the discharge of nitrogen is subject to regular diurnal variations; that it is largest when food is albuminous and abundant; that it is diminished rapidly by inanition, gradually by a diet containing a large proportion of carbonic hydrates; and that it is increased by ingestion of water, sodic chloride, and ammonium salts. When the quantity of nitrogen discharged is equal to the quantity which enters in food, the body is said to be in "nitrogen equilibrium". Muscular exertion has no marked effect either in increasing the amount or disturbing the equilibrium of the nitrogen exchange.

Uric acid exists in urine chiefly as an acid sodium salt, which is deposited in the cold. When this is decomposed by a stronger acid the free acid crystallizes. Ammonium urate occurs only in ammoniacal urine. When warmed with nitric acid, uric acid leaves on evaporation a brick-red stain, which is reddened by ammonia. Uric acid reduces cupric hydrate, potassium permanganate, plumbic peroxide, &c.

The daily discharge of uric acid is increased by certain kinds of dyspepsia, in fever, and in certain chronic diseases.

It undergoes oxidation into urea and oxalic acid in the body. *Xanthin* is a neutral body allied to uric acid which exists in urine, and is distinguished by the yellow residue left when it is heated with nitric acid. *Allantoin* is associated with oxalic acid as an oxidation product of uric acid. It exists in all fœtal urine, and in that of some adult animals. *Hippuric ccid,* the chief constituent of the urine of the graminivora, probably originates in most animals by the ingestion of benzoic acid or of bodies which yield benzoic acid in the organism.

Human urine contains a soluble yellow colouring matter (urochrome) which is precipitated from its solution by acetate of lead. The precipitate when decomposed with dilute sulphuric acid yields a yellow solution. Urine also usually contains a colourless chromogenous substance, which when treated with hydrochloric acid yields indigo-blue. Grape sugar exists normally in urine but in very small quantity. As, however, both uric acid and creatinine reduce cupric oxide, the presence of sugar cannot be proved by the copper test unless these bodies have been previously removed.

The materials which constitute urinary deposits and concretions may be divided into those of acid and of alkaline urine, the former comprising uric acid, urates, and calcic oxalate, the latter the calcic and magnesic phosphates, triple phosphate and calcic carbonate.

EXCHANGE OF MATERIAL.

The term "exchange of material" is used to denote the chemical process which constitutes the life of the animal body. As it is made up of the chemical processes ("functions") which go on in each organ, its activity is dependent on the activity of each of the functions which constitute it. Its total amount is known by the direct and indirect measurement of the daily income and expenditure of carbon, hydrogen, nitrogen and oxygen respectively, in an animal of which the weight is constant. A diet which is sufficient, and not more than sufficient for the maintenance of the weight of the body without either loss or gain, is said to be "adequate." The condition of the organism in which the weight is constant and the diet not more than adequate, is spoken of as that of "nutritive equilibrium."

[Example 1. An adult male in nutritive equilibrium weighing 74 kilogrammes, took in food daily about 15·5 grammes of nitrogen and 225 grammes of carbon. Of the nitrogen he discharged 93 per cent. in the urine, the rest in the fæces. Of the carbon about the same proportion as carbonic anhydride, in respiration. These quantities were yielded by a diet consisting chiefly of meat and bread, with the addition of smaller quantities of potatoes, butter, eggs, &c., and comprising 100 grammes of albumin, 100 grammes of fat, and 250 grammes of carbonic hydrates].

In inanition the body feeds upon itself: the exchange therefore differs according to the proportion of nutritive elements and particularly fat, which the tissues contain. In prolonged inanition the fat wastes first, and eventually almost disappears. The glandular organs (particularly the liver), eventually waste to about a half, the blood and the muscles to about a third of their original weight. The loss of weight is at first very rapid, the rate being proportional to the quantity of store material. As the store is exhausted the waste becomes more uniform.

[Example 2. In inanition the person referred to in example 1, previously in equilibrium, discharged in 24 hours 8 grammes of nitrogen and 184 grammes of carbon, of which all but 2 per cent. was in carbonic anhydride. To yield these quantities, about 50 grammes of the albumin of the body, and 156 grammes of the fat must have been disintegrated. During the period of observation, which began 24 hours after the last meal, 1·4 per cent. of body-weight was lost.]

In fever, the exchange of material resembles that of inanition, but the disintegration of albumin is much more rapid.

A diet consisting exclusively of albuminous substances would be disadvantageous, because the quantity of such material necessary to supply sufficient carbon for respiration (about 200 grammes of carbon per diem) would be greater than can be advantageously disposed of in the organism. Thus about 420 grammes of albumin would be required, which in disintegration would yield 140 grammes of urea and uric acid.

[EXAMPLE 3. The same person on an abundant diet of 1832 grammes of meat with 70 grammes of fat, ingested 62·3 grammes of nitrogen, and 229·3 of carbon daily; he discharged 86·3 grammes of urea, and 2 grammes of uric acid. The total amount of nitrogen excreted was 44 grammes. Of carbon, 231 grammes. were discharged as carbonic acid, and 32 grammes by urine and fæces. In this case 18 grammes of nitrogen, *i.e.* 54 grammes of albumin were retained in the organism, which notwithstanding lost weight, in consequence of the disintegration of fat.]

A fat diet is favourable to integration. The carbonic hydrates act similarly, but larger quantities must be used. It is not proved that carbonic hydrates can be transformed into fat. A diet in which albuminous substances are replaced by gelatin or collagenous substance, is inadequate. Gelatin is capable of disintegration, not of integration.

A diet in which albuminous substances exist, but in too small proportion, is inadequate, not merely for want of albumin but because the digestion of its non-nitrogenous nutritive constituents is impaired.

In man, disintegration takes place at about the same rate when the diet is exclusively non-nitrogenous, as in inanition, but there is no corresponding loss of body-weight.

TABLE II.

Adequate Diet. Male, weight 74 kilogrammes.

		Nitrogen.	Carbon.
Meat	250 grammes.	8·5 grammes.	31·8 grammes.
Bread	400 ,,	5·1 ,,	97·4 ,,
Starch	70 ,,	0·0 ,,	26·0 ,,
White of Egg ...	70 ,,	1·5 ,,	6·0 ,,
Butter and Lard	100 ,,	0·1 ,,	67·9 ,,
Salt	10 ,,	0·1 ,,	
Water	2100		
		15·3	229·1

TABLE III.

Exchange of Material on Adequate Diet.

INCOME.

		Nitrogen.	Carbon.
Albumin	100 grammes.	15·5 grammes.	53·0 grammes.
Fat	100 ,,	0·0 ,,	79·0 ,,
Carbonic hydrates	250 ,,	0·0 ,,	93·0 ,,
		15·5	225·0

EXPENDITURE.

Urea	31·5 grammes	... ... 14·4 grammes.	6·16 grammes.
Uric Acid	0·5 ,,		
Dejecta		1·1 ,,	10·84 ,,
Respiration (CO_2)		0·0 ,,	208·0 ,,
		15·5	225·0

Part II.

THE MECHANICAL PROCESSES.

Muscular Contraction.

Muscle consists of parallel fibres, each of which is a tube containing protoplasm. In the protoplasm, particles are suspended which are of definite form and have a definite arrangement. During life the tube-content is semi-fluid, and capable of being squeezed out as juice (muscle-plasma), but after death it solidifies and exhibits a tendency to split transversely and longitudinally, in accordance with the arrangement of the particles. Muscle is neutral when living, acid after death. Muscle-plasma coagulates spontaneously at all temperatures above that of freezing. At 40° C. coagulation is instantaneous: the promptitude with which it occurs is the less, the lower the temperature.

The coagulum is myosin. After the separation of the coagulum, the liquid (muscle-serum) contains, besides the crystalline and the non-nitrogenous immediate principles of muscles (extractive matters), common albumin and other albuminous compounds differing from it, either as regards the temperature at which they coagulate, or in not being coagulable by heat.

The extractive matters of muscle (so-called because found in the aqueous extract) are (1) lactic acid of flesh; (2) inosite; (3) creatin; (4) bodies of the xanthin group. The chemical changes which constitute the life of muscle, manifest themselves in the production of carbonic acid and water. These products are constantly given off by living muscle; but when it is at rest the production is very inconsiderable. During muscular work it is largely increased. In this way carbon, hydrogen and oxygen are given off by living muscle in the proportion in which they are combined in carbonic hydrates, with the addition of two atoms of oxygen for every atom of carbon. Hence muscle requires for its nutrition a carbonic hydrate (probably glycogen), water and oxygen.

Living muscle is elastic, contractile and transparent. As life ceases it stiffens, shortens, loses its contractility, and transparency, and the contents of its fasciculi become solid. Death of muscle is promoted by defective blood supply, high temperature or injury. It is slow and gradual in the frog, rapid and sudden in man and mammalia. It is associated with chemical changes which resemble those which take place in contraction.

In doing work muscle shortens and thickens. Its volume diminishes very slightly and it becomes more extensible. Every muscular contraction results from stimulation either extrinsic or intrinsic. An instantaneous extrinsic stimulation of a muscle by its nerve, produces a single contraction, called a *twitch.* The contraction begins a certain time after the stimulation *(period of latent stimulation)*, it rapidly increases to a maximum and then gradually subsides. After contraction has ceased the muscle is nearly as long as before, and soon quite as long. The period of latent stimulation can be measured either by Pouillet's method or graphically. The graphical method enables us also to measure the duration of the contraction and to judge of its character. Both are affected by cold, heat and by toxical agents. If two instantaneous stimuli follow each other the effect is accumulative.

Continuous stimulation of a muscle by its nerve produces continuous contraction, *(Tetanus)*. Such stimulation may be intrinsic, *i.e.* may originate from a nervous centre, or extrinsic. In the latter case it may be absolutely continuous, or may consist of a rapid succession of instantaneous stimuli, which give rise to a succession of contractions of which the frequency is the same as that of the stimuli. The number of single contractions per second which constitute a tetanic or continuous contraction, is judged of by the 'tone' heard in the contracting muscles. In ordinary muscular contraction in man the rate of vibration is 19·5 per second (Helmholtz). The contraction produced at any point of a "curarized" and extended muscle by instantaneous excitation, progresses from the point excited in the direction of the fibres. In exhausted muscles and in muscles under the influence of cold, this progress is slower than in fresh muscle at the ordinary temperature.

By the term "absolute force" is denoted the heaviest weight a muscle is able *just* to lift, when contracting to the utmost advantage under the influence of an "adequate" stimulus.

The weight which a muscle is able to lift varies according to its extension, being greatest when it is most extended—consequently greater at the beginning of a continuous contraction than at the end. The maximum quantity of work is done by a muscle when it is nearly loaded to the utmost throughout the whole contraction. This can only be the case when the load gradually diminishes at a rate which is proportional to that at which the weight diminishes which it is able to lift. When the load to be lifted remains constant, the muscle acts most advantageously, *(i.e.* does most work), when the weight is considerably less than the maximum weight which the muscle is able to lift.

In contraction the temperature of muscle is slightly raised: the greater the effort and the less the work done, the greater the rise. In rigor it is also raised.

The muscle current.—Living muscle is electromotive. When the cut surface of a living muscle is connected by a suitable conductor with the natural longitudinal surface, a current is found to exist in the conductor, of which the direction is from the longitudinal to the cut surface.

The electromotive force of living frog muscle has been investigated by Du Bois Reymond (galvanometrically), and by Engelmann (with the aid of Thompson's electrometer).

According to both observers it may exceed $\frac{1}{150}$ of the electromotive force of a Daniell's element.*

When a cylinder of living muscle is investigated, the greatest "deflection" is obtained when one electrode is applied to the equator of the longitudinal surface, and the other to the centre of the cut surface. When the muscle-cylinder is bevelled, the greatest difference manifests itself between the blunt and the sharp edge. When muscle is excited, the contracted part becomes negative to the non-contracted part. If a muscle is tetanized by continued stimulation, the muscle current disappears or diminishes. This change shows itself galvanometrically by the return of the needle towards zero. It is referred to as the "negative variation" of the muscle-current. In instantaneous stimulation the effect is of such short duration that it is more difficult to observe. It can, however, be demonstrated either by the galvanometer, or by the rheoscopic limb of the frog.

Of the electrical phenomena of muscle there are two theories, more or less opposed to each other, viz:—that of Du Bois Reymond, according to which muscle is conceived of as containing so-called "electrical molecules" suspended in a conducting liquid in parallel series, end to end, of which the ends possess negative tension and the sides positive; and that of Hermann—that the negative tension of the cut surface and that of muscle when in the state which precedes contraction (latent stimulation), is in each instance the expression of the impairment of the life of the parts in which such negative tension manifests itself.

The electrical phenomena of muscle are inseparably associated with its life, but it is not as yet known what quantitative relation (if any) exists between the electromotive force of muscle and its capacity for doing work.

Muscle possesses a property of contracting when excited which is independent of its nerves. In evidence of this the following facts are referred to:—(1) Muscle of which the nerves have undergone disintegration, are notwithstanding contractile. (2) This is also observed in muscles of which the nerves have been deprived of their functional activity by toxical agents. (3) In both instances, such muscles re-act to stimuli (particularly electrical stimuli) differently from normal muscles. (4) Muscles which possess no nerves are contractile.

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* There is reason to believe that this estimate will be found to be excessive.

Summary.—In the life of muscle we may distinguish four physiological states—those of latent excitation, contraction, restitution and "tonus." In latent excitation electromotive force disappears. In contraction heat is liberated, work is done (each of these two products being replaceable by an equivalent quantity of the other) chemical dissociation takes place, and excitability is lost. In restitution chemical integration occurs and is accompanied by the disappearance of as much heat as was before liberated, or converted into work, and excitability is restored.. Tonus is what we call rest; for our muscles are constantly in effort even when they do not work. The state of absolute rest of living muscle is unknown.

In involuntary muscle, the process of contraction is similar but much slower. It is attended with the same electrical changes as in voluntary muscle. The contraction of the muscular tissue of the heart, is intermediate in character and duration between that of striped and unstriped muscle.

CIRCULATION.

The arterial circulation.—The systemic arterial system is an elastic receptacle for blood, the form of which is dendritic. By the capillary ends of the ramifications, blood leaks into the venous system. Into the trunk, blood is injected at intervals by the heart; each injection lasts about three-tenths of a second, and is separated from its successor by an intermission of four or five tenths. In the aorta the blood is squeezed by the arterial wall with a pressure of about 5 inches (= 125 millimeters) of mercury = $\frac{1}{6}$ atmosphere = 5 feet 5 inches of water = $2\frac{1}{2}$ lbs. on the square inch. It is this pressure which is the cause of the circulation. Its maintenance is the function of the heart. The sum of the *lumina* of the capillaries is much greater than that of the aorta: the velocity of the capillary blood stream is in the same proportion less. Arterial tissue possesses nearly perfect elasticity. Its elasticity is about $\frac{1}{4}$ of that of muscle, and is greater in the long than in the cross direction. The elasticity of living artery being partly muscular, varies according to the degree of contraction of the muscular elements it contains.

The arterial blood-stream can be best understood by reference to schemata.

Schema 1. As regards the relation of pressure to progressive motion, the arterial system is represented by a Mariotte's bottle from which water flows through a horizontal tube of equal width throughout. In the arterial system, as in the schema, the lateral pressure (supposing the velocity of the blood stream to be constant) is proportional to the sum of the resistances in front. If a Mariotte's bottle having an aperture equal to the lumen of the aorta, were connected with that trunk, the height to which it would be necessary to fill it with blood in order to carry on the circulation at the normal rate, would represent the force required for that purpose. That height multiplied by the weight of of blood discharged per second in grammes, would give in kilogrammeters the work done per minute in maintaining the circulation.

Schema 2. As regards wave motion, or pulsation, it is represented by an elastic tube, *a*, *b*, closed at both ends and moderately distended with liquid, into which water is suddenly and for a short time injected. The phenomena observed remain unaltered, if, instead of closing the tube at its ends, we imitate the conditions of the circulation by injecting liquid into it at short intervals at *a*, allowing it to flow out by a small opening at *b*.

In the arterial system just as in schema 2, the instantaneous distension produced in the aorta by each injection of blood, is propagated to other parts of the system at a rate which increases as the arterial pressure diminishes. Every such sudden distension is followed by a reflex (second beat).

The elasticity of the arteries can be shown experimentally to be advantageous. It is so because (1) when a liquid is violently injected at short intervals (as by the heart) into a rigid tube, much motion is lost by the shock of the liquid against the inexpansible tube-wall; but (2) if the tube is elastic, the motion is stored up as elastic force during the shock, again to resume the form of motion during the interval.

Investigation of arterial pressure.—The hæmadynamometer is a mercurial manometer of which one limb can be connected with an artery by a tube containing solution of sodic carbonate. In order that the measurement be accurate it is necessary (1) that the mean level of the mercury surface in the proximal limb should be the same as that of the arterial aperture; and (2) that the tube should enter the artery at right angles to its axis.

Any instrument by which the arterial pressure can be measured, and at the same time written on a surface moving horizontally by clockwork at a uniform rate, is called a kymograph. A mercurial kymograph consists of three parts—The clock-work and recording cylinder; the manometer and writer; the tube and cannula by which it is connected with the artery. Its uses are (1) to measure the mean arterial pressure and to record its variations; (2) to measure the duration of the pulsation intervals. Its chief defect arises from the "proper motion" of the mercurial column. The spring kymograph on Bourdon's principle is nearly free from "proper motion," and consequently enables us to measure the fine variations of arterial pressure in the course of each pulse interval.

The pulse as felt by the finger indicates the moment of greatest distension, *i. e.* that of greatest pressure in the artery. The distinctness with which it is felt is proportional to the shock communicated to the arteries by the heart. Pulses are classified according to frequency, hardness, duration and dicrotism. All of these characters may be appreciated by the finger, but are studied more accurately by the sphygmograph.

Unnatural *frequency* of pulse usually depends either on functional disturbance of the cerebro-spinal centres or increased bodily temperature (pyrexia). Unnatural *celerity* of pulse, *i.e.* diminished duration of the period of expansion, is observed (1) in pyrexia, (2) during muscular exhaustion, (3) in consequence of mechanical defect of the aortic valve, (4) under the influence of amyl nitrite. The opposite condition (tardiness of pulse) occurs in advanced age, in collapse and under the influence of certain drugs particularly of opium and digitalis. The arterial blood-stream can, under certain circumstances, be heard.

Velocity of the circulation.—The velocity of the blood-stream is dependent on the relation of the effort made by the heart to the resistance to be overcome in the vessels. This resistance is in part dependent on "tonus" but it does not follow that increase of tonus leads to diminished circulation.

Of the instruments used for investigating the progressive movement of blood in the arteries, those by which the quantity conveyed can be estimated are called Dromometers (*e.g.* Volkmann's and Ludwig's), those by which the rate of movement only is determined, Tachometers. By the latter we learn that in the large arteries the second beat or expansion is attended by a cessation or even reversal of the blood-stream; by the former, that the rate at which blood is transmitted through an artery, is subject to great and often sudden variations, and that these variations are independent of the rate at which blood is discharged into the arterial system by the heart.

Capillary circulation.—In studying the circulation in the transparent parts of animals, we observe that the smallest arteries are subject to great variations of diameter and often contract rhythmically; that the progressive movement in arterioles is more rapid than in veins of corresponding size; that in the veins the coloured corpuscles are carried along by the axial stream, the leucocytes tending towards the vascular wall; that when a tissue is injured the capillaries begin first to widen and then to leak, the plasma, and leucocytes passing out in succession; that more intense injury produces stasis and extravasion of the coloured disks.

Renal circulation.—In the kidney the circulation is modified to suit the function of the organ. In the capillary system of the glomeruli, the stream is rapid and the pressure arterial. In that of the tubes, the current is slow and the pressure that of the venous system. These facts are in relation with the mechanism of uropoiesis, which is a process partly of filtration, partly of secretion.

Hepatic and splenic circulation.—In the liver and spleen the rate of transmission of blood is subject to great variations, the effects of which show themselves in variations of the quantity of blood contained in these organs at a time, and consequently of their bulk. In both organs these variations depend in great measure on mechanical causes.

Venous circulation.—The capacity of the venous system much exceeds that of the arterial, and is sufficient for the reception of the whole of the circulating blood. The mean lateral pressure in the venous system, though much inferior to that which exists in the arteries, is dependent on it and varies with it. It is greater in the capillary veins than in the venous trunks: this difference is the chief cause of the venous blood-stream. It is greater during inspiration than during expiration. This difference is more marked in the intra-thoracic veins (where during inspiration the lateral pressure sinks below that of the atmosphere) than in others: it manifests itself in the respiratory movements of the brain, and other similar phenomena. The venous blood-stream is promoted by intermittent external pressure, hindered by continuous pressure. It is considerably influenced by gravity.

Veins are contractile, but there is no proof that their contractility is of physiological importance in man. In certain animals, the veins contract rhythmically.

The lymphatic system.—The absorbents or lymphatics originate from the tissue interstices, to which they constitute a system of drains. Solid particles, if of sufficient minuteness, whether introduced into the blood-stream or into the tissues, find their way into the lymphatics, which can be "injected" by the introduction of any particulate liquid into living tissue. It is probable that such particles are arrested in the lymph glands. In all muscular parts, the flow of lymph is determined by the alternate tension and relaxation of the tendons and aponeuroses. This fact stands in relation with the anatomical fact that these structures are invested by a rich net-work of lymphatic vessels with which their interfascicular splits communicate. The lymphatics of tendons derive their lymph from the muscles. In the abdomen and thorax the flow of lymph is promoted not only by the difference of pressure between the two cavities, but also by the successive variations of pressure to which the lymphatic trunks are subjected.

THE HEART.

With the exception of Amphioxus, all vertebrates have hearts, *i.e.* muscular dilatations provided with a valve or valves at either opening, and a venous ante-chamber or reservoir. In the lower vertebrates the ante-chamber is more perfect than in man and mammalia. In the osseous fishes another dilatation (the bulbus arteriosus) exists between the ventricle and the branchial arteries, the function of which is to store up *vis viva* during the ventricular systole, as the arteries do in mammals (*e.g.* carp, cod, &c.) In the cartilaginous fishes the bulb is a muscular organ in which *vis viva* originates, and it is often provided with valves. These complications in the structure of the central organ are rendered necessary by the simplicity of the circulation. In the batrachians the bulb is less required, for only part of the heart-stream passes through the respiratory apparatus, but the auricles are still provided with valves. In the mammalian heart, the mechanism of respiration renders the auricular valves unnecessary.

Motions of the heart and phenomena which accompany them.—The form of the contracted heart is that of a cone, of which the base is elliptical and the apex rounded off: in the relaxed state the heart assumes the form of the wedge-shaped space in which it is contained. It approaches the anterior wall of the chest in expiration, recedes in inspiration.

In systole the heart suddenly draws itself together towards a part of the septum which is $\frac{2}{3}$ of the way from the ariculo-ventricular groove to the apex (region of rest). On grasping the contracting heart it is felt to widen and become harder. The impulse is due to these changes of form and consistence. It is felt most strongly between the fifth and sixth cartilages.

Each heart period is divided into two parts, the period of repose and that of action. The period of rest commences with the closure of the sigmoid valve. Its duration varies according to the frequency of the contractions. During the whole of it, the cavities fill with blood.

The period of action, of which the duration in man is about four-tenths of a second, commences with the auricular systole. About one-tenth of a second later, the ventricular systole occurs: thereupon the auriculo-ventricular valves close and the blood is suddenly ejected into the aorta and pulmonary artery. At the end of its systole, which lasts about three tenths of a second, the ventricle suddenly relaxes.

The lateral pressure in the auricles is about equal to that of the atmosphere. It rises, however, slightly in auricular systole, attaining its maximum at the commencement of ventricular systole. In the ventricles it sinks below that of the atmosphere immediately after the sigmoid valves close;

at the moment of systole it rises above the pressure in the aorta.

The first sound is produced by two causes, the muscular contraction and the sudden tightening of the heart. The second sound is due to the tightening of the aorta and sigmoid valves.

The mechanism of the filling of the heart in diastole is insufficiently understood. It is accounted for by Brücke on the assumption that when the aortic pressure is greater than the intra-ventricular, the coronary arteries are distended and distend the heart. By others it is attributed to the influence of pulmonary elasticity, *i.e.* to the fact that the "intra-thoracic pressure" is always inferior to that of the atmosphere. This explanation is, however, inadequate.

The work done by the left ventricle in each systole is equal to the sum of the work required to overcome the total resistance in the vessels (*i.e.* the product of the weight of blood discharged and the height of a column of blood corresponding to the aortic pressure) in addition to the work which the ventricle would do in discharging its contents if the aortic pressure were equal to that of the atmosphere. It is estimated at about half a kilogrammeter.

RESPIRATION.

Pulmonary respiration presents itself for the first time in the animal series, in the Batrachians. In the frog, pulmonary inspiration consists in the injection of air contained in the closed pharynx by the contraction of the muscles of its floor. In expiration the lungs are compressed by the muscles of the flanks. In reptiles and birds the mechanism of respiration resembles that of mammals, but in the former the pause occurs between inspiration and expiration; in the latter the pulmonary cavity communicates with extra thoracic reservoirs from which air enters in inspiration.

The ordinary muscles of inspiration are the diaphragm, intercostals, and levatores costarum : the auxiliary muscles are the scaleni, sterno-mastoids, serrati, subclavian and pectorales. In each ordinary contraction of the diaphragm its centrum tendineum descends about $\frac{2}{3}$ of an inch. Its efficiency in expanding the thorax, depends on the facility with which air enters, and the elasticity of the lungs. When it acts inefficiently (as in emphysema or laryngeal stenosis), it draws the ribs towards the spinal column. The diaphragm is the most important voluntary muscle of the body.

Tho external intercostals and intercartilaginous internal intercostals are known by direct observation to be muscles of inspiration.

Of the auxiliary muscles, those which increase the vertical diameter of the chest are the most important. They act only in dyspnœa, in which condition thoracic inspiration is accompanied by associated movements of the mouth, fauces and larynx. Such movements occur normally in animals.

Normal expiration is due almost entirely to the elasticity of the lungs and of the walls of the thorax; but in dyspnœa the expiratory muscles come into action, viz., the muscles of the abdominal wall, the quadratus lumborum, the triangularis sterni, and probably the interosseous internal intercostals.

The lungs, mechanically considered, may be regarded as a collection of elastic and very distensible bags, all of which communicate freely with each other as well as with the atmosphere. The volume of the lung, when left to itself, is much smaller than that of the cavity in which it is contained and which it completely fills; consequently when a pleural cavity is opened the lung collapses. When it is brought into communication with a mercurial manometer, the column in the open limb falls. If while the pleural cavities are still closed the trachea is connected with a manometer, the difference observed on perforating the pleura will be about the same, but the column in the open limb will be higher than the other. As measured when the respiratory muscles are relaxed, this difference usually amounts to about $\frac{1}{100}$ of an atmosphere (7 millimeters of mercury). In natural inspiration it increases to 8 or 9 millimeters, and diminishes in expiration to 0. In full inspiration it may be increased to 30 millimeters.

It is increased by any cause which destroys the expansibility of any part of the lung.

In inspiration the diastolic filling out of the heart is favoured. Consequently the heart contracts with more effect after each inspiration, and the arterial pressure rises.

The changes of form of the thorax produced by the action of the respiratory muscles may be determined by the measurement of the diameters of the chest. Thus in an adult male, from the upper end of the sternum to the third dorsal spine, the chest measures at the end of expiration about 150 millimeters; from the lower end of the sternum to the eighth spine about 200 millimeters; from the eighth rib on the right side in the axillary line to the same point on the left side, about 230 millimeters. Tho first of these diameters increases about one millimeter, the second about two, and the third about 2½ millimeters in ordinary inspiration. These measurements when recorded graphically yield the respiratory curve or tracing.

An adult male inspires about 500 cubic centimeters, (30·5 cubic inches) at a time, and about 19 times per minute; consequently 579 cubic inches per minute. The greatest volume of air which an individual is able to exchange in a breath is called the "vital capacity." The mean "vital capacity" of a man of ordinary height and build (5 feet 7 inches) is 230 cubic inches = 3770 cubic centimeters. From observations made on a large number of male adults, it has been found that on the whole the vital capacity varies according to height and chest girth, in such a way that for every inch by which the height exceeds 150 centimeters (5 feet), and the girth 65 centimeters (26 inches), it is estimated that the vital capacity increases by 150 cubic centimeters, but in individual instances this result is much affected by the flexibility of the chest, the muscularity of the individual and other circumstances the influence of which it is difficult to estimate.

After the most complete expiration possible, a quantity of air remains in the thorax which is sometimes called "residual" and amounts to about 1400 cubic centimeters. After ordinary expiration the chest contains some 3000 cubic centimeters more.

Two sounds are heard in listening to the normal chest, viz., the vesicular inspiration sound, and the bronchial sound which is chiefly expiratory. The former has its seat in the *infundibula*, the latter in the *rima glottidis*. In each case the production of the sound is dependent on the sudden widening of the channel along which the air flows.

Bodily Motion.

Action of voluntary muscles on the skeleton.—With the exception of those cases in which voluntary muscles act peristaltically, the effect of muscular contraction in producing motions of the whole body or of parts of it, is always dependent on approximation of the ends of the muscles concerned. The direction and extent of these motions are regulated by the forms of the moveable bones, and of the joints by which they are connected with the rest of the skeleton.

Joints are divisible into those which have a single axis of movement (hinge joints) and those which have several axes (ball and socket joints). It is essential to the efficient working of a joint of either kind (1) that the two surfaces should be kept in apposition; and (2) that the movements of the bones on each other should be restrained within due limits; accordingly, contrivances exist in all joints for these two purposes.

In the action of a muscle in producing motion about a joint, the work done never represents the *whole* of the force exerted by the muscle, part being always wasted against resistance, *i.e.* converted into heat. In all cases the effect produced is to the force exerted, as the *distance of the nearest point of the contracting muscle from the axis of rotation of the joint* is to the *distance from the joint to the insertion of the muscle.*

The maintenance of the erect posture is dependent on constant muscular exertion, for the line of gravity of the head falls far *in front* of the condyles of the occipital bone, that of the head and trunk together *behind* the line which joins the hip joints, that of the whole body, *in front* of the ankle joint. As regards each of these parts, excepting the head, the supporting muscles are aided by the forms of the joints and the arrangement of the ligaments. In sitting, the body if unsupported in front or behind is balanced on the *tubera ischii.*

In walking, the position of the advancing or acting limb at the beginning of each step, is represented by the *vertical,* the following limb by the *hypothenuse* of a right angled triangle, of which the base is a step or pace, and the apex is in the position of the hip-joint: at the same moment the knee and ankle joints are flexed. Towards the end of each step, both joints become strongly extended. Even in walking there is an interval during which the weight of the body is unsupported: as the pace quickens this interval lengthens. During each step the pressure of the foot upon the ground increases towards the end: the pelvis oscillates once from side to side and twice up and down, for every two paces, *i.e.* in each period of progression.

VOICE AND SPEECH.

THE movements of the thyroid and arytenoid cartilages by which the form of the glottis and the tension of the cords are modified, are (1) rotation of the thyroid on its horizontal axis; (2) rotation of each arytenoid on its vertical axis; and (3) rotation of each arytenoid on its horizontal axis. The first produces tightening of the cords, the second, closure of the vocal glottis the respiratory remaining open, and the third, dilatation of both.

Voice.—It is the principal function of the glottis to produce those compound musical tones to which in physiology we apply the term "voice." These when modified by the mouth so as to become articulate, constitute "speech". Articulation consists in the production of certain sounds in the mouth and pharynx which are either associated with voice (as in speaking aloud), or constitute all that is heard (as in whispering). These sounds are distinguished as vowels and consonants. Vowel sounds differ from consonant sounds in possessing the characters of musical tones. Each vowel has its own pitch or tone. To produce any vowel sound, such form must be given to the cavity of the mouth and pharynx as to render it a "resonator" for the "tone" which is characteristic of the vowel to be produced. For the perfect production of a vowel sound it is necessary that it should be a constituent of the voice sound. Consonants are modifications of the voice or whisper caused by the passage of air through constricted or valvular parts of the mouth or fauces. They are produced by the soft palate, tongue or lips. They are divisible into four groups, viz. (1) valve sounds, (2) blowing sounds, (3) nasal sounds, (4) vibrating sounds. Of these groups each of the sounds belonging to the first and second, presents itself in a soft and a hard modification, of which the former can only be produced *aloud*.

PART III.

FUNCTIONS OF THE NERVOUS SYSTEM.

NERVES.

The organs of the nervous system of which the functions are known are (1) Reflex centres; (2) End-organs; and (3) Conducting organs. The most important conducting organs are nerves. A nerve is made up of fibres, each of which consists of axis cylinder, medullary sheath and nucleated sheath. The medullary sheath is divided into lengths by septa at equal intervals, but the axis cylinder is continuous. The axis cylinder consists of protoplasm.

The medullary sheath is made up largely of material soluble in ether. This material consists of cholesterin, and of a body which yields, when boiled with baryta water, neurin, baric glycerophosphate, and barium compounds of fatty acids. This body is called Lecithin.

Of the chemical process in nerve we know nothing.

The conducting function of nerve depends on its "excitability". The excitability of nerve is greater than that of muscle; it at first increases after severance from the centre, but afterwards declines as the nerve dies (Ritter and Valli); it diminishes by want of use, is exhausted by over-use, destroyed by injury; it is at first increased, then diminished by temperature above the normal.

Influence of the voltaic current on nerve. (1.) Under the influence of a constant current flowing along a nerve, its excitability is increased near the negative pole (cathelectrotonos), decreased near the positive pole (analectrotonos), but the nerve is not excited so long as the intensity does not vary. (2.) Every variation of intensity of a current so directed excites the nerve. No effect is produced if the current is transverse. (3.) If the current is of moderate intensity, the excitation occurs at make and break whatever its direction—the make excitation starting from the Cathode, the break from the Anode. (4.) If the current is strong, the make excitation is suppressed when the current is from the muscle; the break excitation when it is towards the muscle. (5.) If the current is weak, there is no excitation excepting at make. The preceding propositions constitute the so-called "Law of contraction." (Pflüger).

Methods and Processes of Stimulation.—(1) A motor nerve may be excited by the closing or opening of a voltaic current flowing along it; (2) by any change in the intensity of such a current; (3) by the flashing along it of an induction current; (4) by the flashing of a succession of induction currents in alternately opposite directions (Faradization); (5) mechanically—either by a single percussion or by a rapid succession of them (Heidenhain;) (6) by chemical agents which either deprive the nerve of water or disintegrate it.

In all measurable modes of stimulation, the muscular effect increases with the stimulus up to a certain limit, beyond which there is no further augment. Stimuli just sufficient to produce the maximum effect are called "maximal"; others "over maximal" or "minimal" as the case may be. The effect of a minimal stimulus is increased when the seat of stimulation is in *cathelectrotonos;* the effect of a maximal is diminished when it is in *analectrotonos.*

Living nerve is electromotive. The phenomena closely agree with those of muscle and are in conformity with the second theory given on p. 38. The electromotive force between cut and natural surface of nerve is believed to be nearly twice as great as in muscle.

Electrotonic variation of the nerve current.—If during the passage of the voltaic current through the central part of a length of nerve, the extra-polar parts are connected with the galvanometer, currents show themselves which have the same direction as the intra-polar current.

FUNCTIONS OF NERVOUS CENTRES.

Nervous centres owe their physiological endowments to the nucleated cells which are their anatomical characteristics. They exercise their influence on each other and on certain tissues, particularly those of muscle and glands. They are influenced by each other and by excitation of their nerves.

Ganglia. The simplest centres, both as regards structure and function, are those which are called ganglia. These exist in all rhythmically contracting organs *e.g.* in the heart, the intestine and the arteries. They have been chiefly studied in the heart of the frog. In this organ the muscular fibres derive their power of contracting rhythmically after its removal from the body, from the ganglia they contain. Their mode of action may be provisionally understood thus: —Nervous "energy" accumulates in them as long as life continues. Its discharge, (which manifests itself in contraction) occurs at intervals, (1) because it is resisted, and (2) because the capacity of the ganglion for nervous energy is limited. In addition to the motor ganglia, the heart of the frog contains ganglia which are directly connected with the terminations of cardiac branches of the vagi. With reference to the ganglia it is known experimentally (1) that the rhythmical motions of the auricles and ventricles are dependent on those of the sinus, and (2) that the ganglia at the ends of the vagus can be paralysed without affecting the rhythmical motions of the heart, but that when they are excited these motions are arrested or retarded.

By reference to tho functions of the ganglia we are enabled more or less to understand the influence exercised by external agents on the heart, particularly those of variations of temperature and of certain bodies known as "heart poisons." Thus, when the temperature to which the heart of the frog is exposed, is gradually increased from 0° to 40° C. the frequency of the contractions increases until at last the heart stops in "heat rigor," the effect of each systole diminishing as the frequency increases. Of the heart poisons some act through the inhibitory ganglia exclusively (Atropine, Muscarine, Physostigmine, and Nicotine); others on motor and inhibitory ganglia simultaneously (Digitaline, and Aconitine); others exclusively on the motor ganglia (Antiarine and Veratrine).

The functions of the ganglia of the arteries as well as those of the stomach and intestines are probably analogous to those of the motor ganglia of the heart.

Centres of the Spinal Cord.

The posterior roots of the spinal nerves are the channels by which the brain and cord are influenced by peripheral parts; the anterior roots are the channels by which they influence those parts (Majendie). These facts are expressed by the words efferent and afferent as applied to the anterior and posterior roots respectively.

In the frog the former are exclusively efferent, but in mammalia it is observed that after section of the anterior root, excitation of its peripheral end influences the cord. The channel through which the influence is conveyed is the posterior root (Majendie). It is also observed that section of the posterior root diminishes the excitability of the efferent fibres of the anterior root (Ludwig and Cyon).

The relation between the functions of the posterior roots and those of their ganglia is not known. It is known however that these structures exercise a remarkable influence on their nutrition.

The difference between motor and sensory nerves does not appear to depend on inherent difference of function. This is indicated (1) by observations relating to the transmission of the negative variation, (2) by the artificial conversion of a motor into a sensory nerve, and (3) by certain facts relating to the excitation of muscular nerves.

By the term "reflex action" is denoted the process by which the contraction of a muscle, the secretion of a gland, or an electrical discharge is produced when the afferent nerves leading to the centre from which the muscle, gland, or electrical organ receives its motor nerves are excited. The principal facts relating to reflex motions in the frog are the following:—(1) All reflex motions manifest themselves with greater intensity after removal of the intra-cranial nervous system: (2) if the excitation is very slight the area of reflex effect is limited to the region stimulated: (3) most reflexes have a defensive character: (4) many are apparently purposive.

Motor centres of the spinal cord in man and in the higher animals. Centres for various complicated reflex acts connected with the functions of the pelvic organs exist in the lumbar part of the spinal cord. The independence of these acts is proved by the completeness with which they are performed after section of the cord. The following are the most important. (1) The dilatation of the arteries of the erectile organs which gives rise to their distension, is controlled by a spinal centre which, while influenced by the intra-cranial nervous system, acts independently of it. Its activity is evoked by the excitation of certain afferent nerves, suspended by the excitation of others. It acts on the motor ganglia of the arteries through the *nervi erigentes* (just as the centre for the salivary secretion acts on the arteries of the salivary glands). (2) The retention of urine in the bladder after death, is dependent on the form and structure of the organ and the elasticity of its orifice. During life this elasticity is aided by muscular tonus, and, when necessary, by the voluntary contraction of the *sphincter vesicæ.* The discharge of urine is normally determined by the voluntary relaxation of the sphincter, and aided by the voluntary contraction of auxiliary muscles, but it may also be accomplished reflexly. (3) Similarly, the discharge of fæces although normally regulated by the will in the same way as that of micturition, may take place under the direction of a motor centre situated in the spinal cord. The reflex contractions of the sphincter differ from the voluntary contractions in being rhythmical. (4) The contractions of the pregnant uterus which resemble other rhythmical contractions in their relation to the nervous system, are controlled by a centre which, like those already referred to, is situated in the lumbar part of the spinal cord. (5) A centre for the regulation of the peristaltic contractions of the intestine exists in the upper part of the cord of which the position has not yet been determined. Its inhibitory influence is conveyed to the ganglia of the intestine by the splanchnics.

[*The spinal cord as a conducting organ.*

The most important anatomical facts relating to the channels by which excitation is transmitted in the spinal cord, are (1) that the fibres of the spinal nerves are not continued to the brain, but communicate with ganglionic cells; (2) that in the anterior roots this communication is direct, mediate in the posterior, *i.e.* through the reticulum; (3) that the anterior roots may be traced through the anterior horns, to the anterior columns of the other side by the white commissure, as well as to the anterior and lateral columns of the same side; (4) that the fibres of the posterior roots divide into two sets, of which the smaller at once lose themselves in the *substantia gelatinosa*, the larger division tending inwards towards the posterior columns, in which some of the fibres appear to acquire a vertical direction.

The most important results of experiment may be stated as follows:—(1) The fibres of the lateral columns are the only channels of influence between the intra-cranial centres and the lower limbs. (2) The afferent fibres by which excitation of either lower extremity influences the intra-cranial centres, are contained in the lateral column of the opposite side. (3) The motor fibres by which the intra cranial centres influence the muscles of either inferior extremity are contained for the most part in the lateral column of the same side. (4) Each lateral column contains inhibitory fibres, the excitation of which is antagonistic to excitation of its motor fibres. (5) Each lateral column contains groups of motor fibres which are specially concerned in the production of co-ordinated movements. These, as well as the inhibitory fibres, are situated in the parts of the lateral columns which adjoin the central grey substance. (6) In general, the fibres of the anterior and posterior columns serve as channels of communication between neighbouring parts of the cord. There is reason, however, for believing that in the lumbar region, the posterior columns contain fibres by which sensory impressions are transmitted to the brain.

The spinal cord is entirely insensible to mechanical stimulation excepting in the immediate neighbourhood of its motor roots. Its grey substance seems to be also wholly insusceptible of electrical stimulation, but its fibres can be excited either by single induction shocks or by faradization.]

Centres of the Medulla Oblongata.

The central canal of the cord opens out into the rhomboidal space, or fourth ventricle, the two grey columns (horns) thus becoming superficial, and assuming such a position that what was before posterior lies outside. In the stratum of grey substance thus exposed are contained the motor centres which preside over the most important functions of the body, namely those of the heart, of the arteries, of the respiratory organs, of the organs of digestion, of speech, and of locomotion. The origins of the nerves concerned in the functions of these centres are in close relation with each other, but nothing precise is known of their anatomical connexions.

The Centre of Locomotion.—General co-ordinated movements of the limbs, resembling those of locomotion, can be determined in mammalian animals by excitation of any part of the surface, so long as the floor of the fourth ventricle (from the calamus scriptorius to the orifice of the aqueduct) is in connection with the cord. After section below the calamus, the reflex effects of excitation are limited to the excited part.

The Nodus Vitalis or Respiratory Centre.—Destruction of the respiratory centre produces instant death in mammalia: destruction of its upper part only, arrests those respiratory movements which are dependent on the facial nerve: destruction of the lower part only, arrests the thoracic movements. The respiratory centre acts automatically, *i.e.* is self-acting, but its activity is affected by the condition of the blood supplied to it, in such a way that although it gradually becomes exhausted when not supplied with arterial blood, the influence which it exercises on the muscles of inspiration varies in the opposite direction with the supply of oxygen. It receives through the vagus trunk two sets of nerve fibres which act upon it antagonistically to each other. Of these, one set are derived from the superior, and (in many animals) from the inferior laryngeal, the other from the pulmonary plexus. The influence of these fibres may be best understood by supposing that the respiratory centre consists of two parts, of which one is inspiratory, the other expiratory; and that the second of these acts antagonistically to the first, *i.e.* exercises an inhibitory influence over it. In ordinary breathing the expiratory centre is inactive. Defective arterialization of the circulating blood produces increased activity of both centres, *i.e.* hyperpnœa. Saturation of the hæmoglobin of the blood with oxygen produces apnœa, *i.e.* cessation of respiratory effort. Excessive hyperpnœa is called *dyspnœa.* When it results in insensibility it is called *asphyxia.* The condition which produces hyperpnœa is not excess of CO_2 but defect of oxygen. This is proved by observing (1) that respiration of an atmosphere containing an excess of CO_2 does not produce hyperpnœa (Rosenthal). (2) That respiration of a gas or gaseous mixture not containing enough oxygen produces hyperpnœa and asphyxia, even though CO_2 may be in defect in the circulation (Pflüger). (3) That the increase of activity of respiration—*i.e.* of the quantity of air respired per minute—produced by the respiration of CO_2, is not greater than that produced by the respiration of nitrogen (Dohmen).

The mode in which defect of oxygen in the blood acts on the respiratory centre is not known. It may be attributed either to the suspension of the activity of some other intracranial inhibitory centre, or to the direct influence of unoxidized, but oxidizable, material in the blood (Pflüger).

The influence of increase of the temperature of the blood on the respiratory movements resembles that of defect of oxygen.

Although the periodical recurrence of the respiratory movements cannot be shown to be dependent on fluctuations either in the chemical state of the blood, or in any other condition affecting the respiratory centre, it is well known that both inspiratory and expiratory movements may be determined reflexly, *i.e.* by excitation of afferent nerves, as for example in the acts of coughing and sneezing. As, however, these acts are excited by special afferent nerves, it is probable that other special centres are concerned in them, acting either in concert with the respiratory centres or independently of them.

The Vaso-motor Centre.—The cerebro-spinal nervous system influences (*i.e.* regulates) the circulation (1) by increasing or diminishing the activity of the heart and (2) by increasing or diminishing the general resistance in the capillaries. This regulation is dependent on the influence which variations of arterial pressure exercise on the nervous centres, either directly, or by means of afferent cardiac nerves.

The apparatus by which regulation is effected consists of (1) the intra-cranial heart centre, (2) the cardiac vagus, (3) the depressor nerve, (4) the vaso-motor centre, (5) the vaso-motor nervous system, (6) the cardiac accelerator nerves.

Excitation of the cardiac vagus produces in mammalia diminished frequency and increased volume of the pulse, with diminished arterial pressure. The influence of excitation of the intra-cranial heart centre is similar. In some animals this influence is constant, so that on section of both nerves the frequency of the pulse is increased, and the arterial pressure much augmented. The intra-cranial heart centre is excited by increase of arterial pressure in the cranium. Such excitation influences the heart through the cardiac vagus. This is proved by comparing the effect of augmentation of the arterial pressure as observed before and after section of both vagi. The heart centre is similarly affected by the circulation of venous blood in the cranium. Accordingly in all forms of dyspnœa the pulse frequency is diminished in proportion to the venosity of the blood.

The vaso-motor centre is situated in the upper part of the floor of the fourth ventricle. The channels of its influence on the arteries are contained in the lateral columns of the spinal cord, from which they extend by the rami communicantes to the ganglia and prævertebral plexuses of the sympathetic system, whence vaso-motor nerves are distributed to the arteries.

Excitation of vaso-motor nerves or of the cord, produces contraction of the arteries to which they are distributed. As almost all arteries receive their innervation from spinal nerves, section of the cord in the neck produces enormous diminution of the arterial pressure, and consequently, alteration in the distribution of the blood and diminution of the velocity of the blood stream. If, after section, the cord is excited electrically the pressure rapidly rises.

Injury of the vaso-motor centre produces glycosuria with increased discharge of urine. The same effect is produced by destruction of the inferior cervical ganglion.

In the combined action of the cardiac and vaso-motor centres, by which the circulation is regulated, over-action of the heart is prevented by the influence of the resulting augmentation of intra-cranial pressure on the heart centre, while over contraction of the vessels is prevented by the influence of the resulting increase of endocardial pressure (through the depressor) on the vaso-motor centre or on some other centre antagonistic to it.

It is not possible to define the anatomical position either of the centre of the inhibitory nerves or of that of the acceleratory nerves. The former are probably derived from the spinal accessory (for, after destruction of the spinal accessory, and "degeneration" of the fibres which spring from it, the heart is unaffected by excitation of the vagus trunk) the latter from the lower cervical and upper dorsal spinal nerves, (for, after section of the cord at the third dorsal vertebra and division of the vagi and sympathetics, excitation of the cord increases frequency without affecting arterial pressure, whereas excitation of the cervical sympathetic is without effect).

The process of excitation of the heart nerves and vascular nerves differs from that of motor nerves in respect of the greater duration both of the "period of latent stimulation" and of the resulting contraction.

Arterial Tonus.—The word "Tonus" is applied to that degree of continuous contraction of the arteries which normally exists, in other words, that which is most advantageous to the circulation. The "adequacy" of the arterial tonus is indicated by the constancy of the blood stream in the capillary arteries.

In the frog it can be seen (1) that by virtue of arterial tonus the capillary circulation continues for some moments after the influence of the heart has been annulled by tightening a ligature round the ventricle; (2) that if tonus is annulled by destruction of the nervous centres, the circulation is arrested though the heart continues to act vigorously; (3) that if excessive arterial contraction is produced by faradization or mechanical excitation of the cord, the blood stream may also be arrested, but that by moderate direct or reflex excitation of the cord the circulation is rendered more active.

In mammalia the general arterial tonus is augmented (1) by electrical or mechanical excitation of the cord; (2) by reflex excitation of the vaso-motor centre; (3) by diminution of bodily temperature; (4) by circulation of blood containing excess of CO_2; (5) by certain drugs, *e.g.* digitalis and atropine.

Increase of tonus affecting the cutaneous circulation only, is produced by exposure to cold, and is observed in the "algide state" in disease.

General diminution of tonus may be produced (1) by excitation of the depressor; (2) by elevation of bodily temperature; (3) under the influence of certain drugs, particularly amyl nitrite. Local diminution is exemplified in blushing. It may be produced by the section of vascular nerves, by the excitation of certain afferent nerves, and by the excitation of certain efferent nerves, which are therefore called vaso-inhibitory or dilating.

Three orders of recurring variations or fluctuations of arterial tonus are met with in animals, viz., (1) irregular fluctuations affecting only particular arteries; (2) irregular fluctuations affecting the whole arterial system; and (3) rhythmical fluctuations of which the rhythm corresponds with that of the respiratory movements.

After severance of a vascular nerve, the arterial tonus, at first abolished, is after a time restored, notwithstanding that the communication between the arteries supplied by it and the vaso-motor centres continues to be interrupted. On this account it is believed that ganglionic structures exist in anatomical relation with the vaso-motor nerves, the influence of which may replace that of the vaso-motor centre.

Influence of the vaso-motor and respiratory centres in regulating the temperature of the body.—Although constancy of bodily temperature is not dependent on the state of the circulation or respiration, discharge of heat at the surface of the body is prevented or diminished by all causes which diminish the velocity of the circulation, and promoted by those of contrary action: it is most of all promoted by increased activity of the sweat glands, and by the increased cutaneous circulation which is associated with this condition. In animals (particularly in the dog) the increase of activity of the respiratory movements which is produced by increase of bodily temperature, also serves as a means of regulation.

Influence of the respiratory movements on the frequency of the contractions of the heart.—In most mammalia each inspiratory act is followed by increased frequency of pulse. This is attributed with most probability to the inhibitory influence of the respiratory centre on the cardiac vagus.

Death by asphyxia.—The process is divisible into two stages. The first stage is characterized by rapidly increasing dyspnœa, contraction of the arteries, increased arterial pressure, and acceleration of the circulation; the second by unconsciousness, contraction followed by dilatation of the pupils, excitation, passing into paralysis, of the cardiac vagus, irregular but violent gasping inspiration, gradual emptying of the arterial system. The immediate cause of death is exhaustion of the heart. The duration of the process is dependent on (1) the quantity of air contained in the respiratory cavity at the moment of occlusion of the air passages, (2) on the *relative* quantity of blood which the animal possesses and the activity of its chemical processes and (3) on the intensity of the struggle made by the animal before it becomes unconscious.

The centre of voice.—The reflex character of the muscular movements concerned in the production of voice, is shown by the fact that in the frog it can be produced at command, after removal of the hemispheres, by gentle pressure on a particular spot of the back.

The centre of deglutition.—The reflex part of the process of deglutition consists in simultaneous concealment of the laryngeal orifice behind the back of the tongue, and closure of the posterior arch of the fauces, followed by constriction of the pharynx and œsophagus. In this combination of muscular movements the motor nerves concerned are derived entirely from the vagus; the same source furnishes the most important afferent nerves, but branches of glossopharyngeal and trigeminus also take part in the process.

Vomiting consists of two acts viz., relaxation of the cardia and compression of the abdominal cavity, the former preceding the latter. As regards the former of these movements, it is known experimentally, that integrity of the vagus nerves and of those superficial muscular fibres of the stomach which are continuous with the outer longitudinal fibres of the œsophagus, and radiate from the cardia underneath the serous membrane, are necessary conditions to its accomplishment (Schiff).

The centre of balance.—The position of the centre on which the maintenance of the balance of the body depends cannot be precisely stated. In the frog, "balance" is lost after removal of the optic lobes. In birds, similar loss both of balance and co-ordination results from removal of the cerebellum. Corresponding phenomena present themselves in mammals (Flourens).

The afferent nerves of balance are probably those of the semi-circular canals, for both in the frog and in birds, the effects observed after destruction of these parts correspond with those produced after ablation of the central organs. In birds destruction of one canal is followed by oscillatory movements of the head, the direction of which depends on that of the canal destroyed. Corresponding phenomena are observed in disease (Menière's disease).

When one of the middle peduncles of the cerebellum is injured, uncontrollable rotation of the body (rolling) takes place to the opposite side. Injury of the crus (tegmentum) on either side produces expressions of pain and spasmodic contraction, followed by paresis of the muscles of the opposite side of the body. With this is associated a condition in which the animal runs in a circle, of which the centre is on its paretic side *(mouvement de manége.)*

The *centre for the motions of the eyeballs and pupils* is in the corpora quadrigemina: excitation of the right half of the organ determines rotation of both eyeballs towards the left, and *vice versâ*. The nerves principally concerned in these movements —the *oculo motorius* and *trochlearis*—originate from the ganglionic cells of the grey substance on either side of the aqueduct, in the same way that spinal motor nerves originate from those of the anterior horn. Severance of the former produces ptosis, persistent external strabismus, slight dilatation of the pupil, and absence of the power of accommodation for near objects. If either nerve is paralysed the power of adjustment to the horizon is lost, so that objects are seen doubly, but in paralysis of the trochlearis, the images can be united by inclining the head to the uninjured side.

The *abducens* is associated in its origin, with the facial, and supplies the external rectus, which also receives motor nerves from the sympathetic system. [When the sympathetic nerve is excited by faradization in the neck, the pupil of the same side dilates, the vessels of the choroid and retina contract, the eyeball projects (from the contraction of Müller's muscle). When the nerve is divided, the opposite results are produced and the eye squints inwards.]

The Trigeminus. The motor part of the 5th nerve originates from the neighbourhood of the aqueduct, is distributed to the muscles of mastication (except the buccinator) and to the tensor tympani, tensor palati, mylohyoid, and anterior belly of digastric. The sensory division supplies all parts of the head excepting the pharynx, internal ear, back of the external ear, and occipital region.

On division of the fifth in the rabbit behind the ganglion, sensation of pain is expressed and the pupils contract. After division the eye no longer winks on the affected side, and the corresponding half of the face becomes insensible. Eventually, inflammatory changes resulting in ulceration take place at the surface of the cornea and in the mucous membranes of the mouth and nares. The afferent fibres of the trigeminus are concerned in several important reflex actions (those of sneezing, lachrymation, salivation, &c.), which have been termed "sensory" to denote the fact that in each of them, the excitation which determines the combined movement is associated with a peculiar "sensation".

The facial nerve. The facial is distributed to the muscles of the face, stylohyoid, posterior belly of digastric, stapedius, and (by the vidian) to the levator palati and azygos. The effects of its destruction in man are paralysis of the muscles of expression, lagophthalmus, asymmetry of the soft palate, and (perhaps) hyperacusis. After destruction of the nerve in its course through the temporal bone, the salivary glands can no longer be excited to reflex secretion.

Both the nerve for the submaxillary gland (the chorda) and that for the parotid (the smaller superficial petrosal) leave the trunk of the facial in the tympanum, and both become associated with branches of the trigeminus. The chorda contains not only secreting fibres but fibres of which excitation determines dilatation of the vessels of the parts (tongue and submaxillary gland) to which they are distributed. The secreting fibres are paralysed by atropine, which leaves the vascular-dilating fibres unaffected. [The rest of the tongue receives vascular-dilating nerves from the glossopharyngeal. Although the vascularity of the mucous membrane to which it is distributed is not in either case affected by section of the nerve, it is markedly increased by excitation (Vulpian)].

The Hemispheres.

Anatomical connexion between the brain and spinal cord.— The three pairs of symmetrical masses, viz., the corpora striata, optic thalami and corpora quadrigemina are connected with the medulla on each side by three equally distinct parts of the crura, viz., the *crusta, tegmentum* and *fillet.* The fibres of the crusta on either side appear to be continuous with those of the anterior pyramids on the same side and thereby with those of the lateral columns of the cord on the opposite side: upwards they pass into the corpus striatum. The tegmentum ends upwards in the optic thalami (its inner fibres crossing, the outer going straight on), and is continuous below with the superior peduncles of the cerebellum (the fibres of which cross) and, by the *fasciculi teretes,* with the fibres of the lateral columns of the cord. The fillet ends upwards for the most part in the corpora quadrigemina, and downwards is in apparent continuity with the olives.

After removal of the hemispheres an animal sees (Longet, Goltz), hears (Flourens), but exhibits no indication of being able to taste or smell. It acts as if subject to emotion and to pain (Flourens, Vulpian). Its attitude and gait are normal, and it is capable of the most complicated combined movements, but it is unconscious and incapable of voluntary effort.—Removal of one hemisphere in animals is followed by paralysis of the opposite side, which is not permanent. In man absence of one hemisphere is not inconsistent with the performance of brain functions. The intelligence of a mammalian animal is proportional to the relation between the sectional area of the crusta and that of the tegmentum and fillet together (Meynert). It is not proportional to the relative weight of the brain. The brain is entirely unexcitable to mechanical stimuli; certain parts of it, however, are susceptible of excitation by the interrupted voltaic current, as well as by faradaic currents of great intensity.

It has been discovered recently that certain spots exist on the surface of the hemispheres of which the excitation leads to combined movements. These were at first called "motor-centres," it being supposed that in the cortical part of the brain organs exist having functions analogous to those of the coordinating centres of the medulla oblongata and mesencephalon. It has now, however, been shown that the motions in question can be produced by excitation of the subjacent parts, *i.e.* of the fibres which radiate from the corpora striata, and that no permanent disorder of motion results from ablation of the centres, the muscles supposed to be influenced by them not being paralysed, although their combined action is less perfect than before.—It has been frequently observed that destruction of the convolutions of the "island" is associated clinically with aphasia, a condition in which the patient although able to articulate, and possessing the power of forming adequate conceptions which he remembers, is unable to word them.

The experimental and clinical facts relating to the subject are not inconsistent with the hypothesis that the channels by which the hemispheres influence the coordination centres in the mesencephalon and medulla, so as to produce combined muscular action, differ according to the nature of the act intended.

COMMON AND SPECIAL SENSATION.

(Functions of end-organs).

Perceptions.—Recognized sensations are divided into those which are painful and not painful; the latter into those of common sensation, vision, hearing, taste, &c., according to the end-organ affected. Each kind may originate subjectively. The end-organs are excited by motions which are for the most part vibratory. Hence the intensity of the excitation can usually be measured. Very feeble excitation of an end-organ is not felt. The intensity which must be attained by any excitation in order to be felt is called the "limen" *(Reizschwelle)*. As regards all excitations of which the intensity exceeds the limen, it is found that the "sensible increment," *(i.e.* the smallest additional excitation that can be felt) is always proportional to the previous excitation. Hence, the sensation produced by any given excitation varies inversely as the intensity of the previous excitation. This proposition is known as "Fechner's Law." It is usually expressed in the words: "The sensation increases proportionally to the logarithm of the intensity of excitation." As regards light the "sensible increment" is to the "previous excitation" as 1 : 100; as regards sound as 1 : 3. As regards vision the liminal intensity has been estimated to be equal to one three-hundredth of that of full-moon light.

It has been proved by recent experiments (Dewar and McKendrick) that with respect to light, the graduation of sensation takes place in the retina.

Between an excitation of any end-organ and a voluntary motion prompted by it, a time elapses which is made up of the time required for recognizing the sensation (perception) and the time required for transforming it into muscular action (intention). This time is about one sixth of a second at the liminal intensity for sound, light and touch. In increasing the intensity above the limen, the time at first diminishes, then increases.

Tactile sensation is regarded as the function of the so-called "tactile corpuscles" of the skin, and of analogous end-organs which exist in the exposed mucous membranes. According to the mode in which the end-organs are affected, tactile sensation is divisible into that of Pressure, that of Temperature and that of Locality. As regards Pressure, all parts of the body are nearly equally sensitive, but the limen differs very considerably. An increment of pressure on any part of the surface must amount to one-third of the previous pressure, to be felt (E. H. Weber). As regards temperature, excitation is dependent on difference above or below the actual temperature of the skin. The liminal intensity is very small. The least sensible increment, as in the last case, is one-third (E.H.W.). The sensation of locality may be tested either by "interrogation," or by measuring the distance at which two points of excitation must be apart in order that they may be felt as two. The distance in millimeters for different regions is as follows:—Tongue 1; Finger-tip 2; Lip 4; Neck 20; Back 60.

Muscular exertion is attended with a "sensation of effort," the relation of which to the work done, (*e.g.* the weight lifted) fellows Fechner's Law, the smallest sensible difference being one-seventeenth (E.H.W.). This fact affords strong ground for believing that the sensation or effort is not dependent on sensation of pressure.

Vision.

In the eye the retina serves as the ground glass screen of the camera obscura, to receive the diminished and inverted "real images" of objects. Its optical properties depend on (1) the form of its three principal refracting surfaces, and (2) the refractive indices of its transparent media. The refractive indices are investigated in the dead eye by the ordinary methods; the curvatures of the refracting surfaces in the living eye, by the ophthalmometer, an instrument founded on the principal that the apparent diameter of an object as seen reflected by a convex surface is proportional to its convexity.

Of the normal eye the radii of curvature, indices of refraction, and dimensions are approximately as follows:—Radius of the corneal surface, 8 millimeters, radius of the anterior surface of lens, 10 millimeters, of posterior surface, 6 millimeters, these surfaces being severally 4 millimeters apart in the axis of the eye; the distance from the posterior surface to the retina, is 13 millimeters. The index of refraction of the aqueous or vitreous humour is 1·35, of the lens 1·42, that of water being 1·336.

By the term "schematic eye" is denoted an eye supposed to be constructed according to these measurements. Such an eye possesses the optical properties which would belong to the normal eye (irrespectively of accommodation) if it were a perfect optical instrument, *i.e.* if its refracting surfaces were spherical, their centres in the same axis, and their transparent media homogeneous.

The reduced eye. By the term "reduced eye" we designate an eye supposed to consist of one medium and to have but one refracting surface—that of the cornea. In such an eye, if the radius of curvature of the cornea is 5·12, and the index of refraction about 1·35, the conditions approach pretty closely to those of the normal eye. In the reduced eye the straight line which passes through the centre of the cornea and the centre of its sphere of curvature is the axis. Rays which are in the same line with a radius of the refracting surface are not refracted: such rays are called principal rays. Any number of rays reaching the cornea from a luminous point at sufficient distance in the axis, are so refracted at the surface that they converge to a point on the other side. This point is called the "conjugate focus." Rays which emanate from a luminous point in a plane including the first, which is vertical to the axis (object plane) converge to a point in the same vertical plane with the conjugate focus (image plane). It thus happens that (as regards flat surfaces of small extent which face the cornea) every point of the object plane is focussed in the image plane, forming there a real inverted image. The further the object plane is from the refracting surface the nearer must be the image plane. The point to which the almost parallel rays which emanate from any very distant point in the axis converge, is called the principal focus. In the unaccommodated eye this point is in the retina.

Scheiner's Experiment. In the reduced or in the normal eye which is not accommodated—*i.e.* accommodated for distance—object-points near the axis and near the eye are not seen distinctly, because the rays which emanate from them converge behind the retina. Hence, every such point is seen as a blurred circle, of which the margin corresponds to that of the pupil. If a diaphragm having two minute apertures at a distance less than that of the width of the pupil, is placed immediately in front of the cornea, the circle is converted into two points.

Accommodation. The eye in the relaxed state is accommodated for distance. Accommodation might be attained either by altering the refractive indices of the media (if this were possible), by compressing the bulb, or by altering the form of the refracting surfaces. It is actually accomplished by the last of these means only. In accommodation the contraction of the tensor choroideæ by increasing the lateral pressure in the posterior chamber, projects the lens forwards, and at the same time by relaxing the zonula, increases its convexity. Accommodation is associated with rotation of the bulb inwards, and with contraction of the pupil. The near limit of accommodation is about five inches: in the normal eye there is no distant limit. In myopia the rays from distant object-points converge (even when the eye is relaxed) in front of the retina. In hypermetropia the eye requires accommodation even for distant objects, while accommodation for near objects is impossible. The former is corrected by concave, the latter by convex lenses. To determine the limits of distinct vision, Scheiner's method is employed: any apparatus for this purpose is called an optometer. The best proof that accommodation is due to change in the form of the lens is obtained by Purkinje's experiment.

The Retina. Light which reaches the retina is partly absorbed, partly reflected back to its source. Consequently, although the cavity of the globe appears under ordinary circumstances dark, it can be illuminated by light which reaches it as if it came from the eye of the observer. Thus if a plate of glass so placed between the observing and the observed eye that light emanating from a luminous source is reflected by it into the observed eye, as if it came from the other, the former appears bright. If it were possible for both eyes to remain relaxed, that is accommodated for extreme distance, a distinct image of the retina would be seen by the observing eye. Under actual conditions this can only be done by the interposition of a concave lens between the observing eye and the mirror. (Helmholtz's Ophthalmoscope).

The perception of light is dependent on the posterior layer of the retina—the rods and cones. The power of distinguishing colours is believed to be due to the cones. All the physiological attributes of colours are consistent with the hypothesis that each spot of the retinal surface (each cone) contains at least three kinds of elements, respectively susceptible to red, blue, or green light; and that sensations of colour originating from any spot of the retina, depend on the relative intensity with which these several kinds of elements are excited (Young, Helmholtz). The physiological relations of colour correspond to their physical relations; for if the colours are arranged on a plane surface around a centre representing white, in such a way that each colour is on the opposite side of the centre to the colour with which it makes white light, it is then found that the colours are arranged in the same order as in the spectrum.

The perception of an *instantaneous* excitation of the retina is not coincident in time with the excitation, but follows it. The perception of *continuous* illumination of uniform intensity progressively diminishes, *i.e.* the retina gradually tires.

Retinal images which persist after light has ceased to enter the eye from the objects corresponding to them, are called "after-images." After-images, although they appear luminous on a dark field, appear dark on a field of the same luminousness as the object from which they originated. The colour of an after-image seen on a bright ground, is complementary to its colour as seen on a dark ground.

The retina can be excited mechanically or electrically.

The excitability of the "blind-spot" is demonstrated by the observation that if two spots, two and a half inches distant from each other are placed at ten inches distance from the eye, the right hand spot becomes invisible whenever the right eye is fixed on the left hand spot. At the fovea the distance which must be given to two points of excitation in order that they may be separately perceived, is less than in other parts. Two points, of which the retinal images are only two micromillimeters (*i.e.* about $\frac{1}{4}$ the width of a blood corpuscle) apart, can be distinguished. The cones are of about the same width.

Entommatic vision. Shadows of objects floating in the media of the eye are distinguished by the retina, when the eye is illuminated from a point which is so near the cornea that the rays in entering the eye become parallel. As thus seen objects behind the pupil may be distinguished from objects in front of it, by the observation that they appear to move in the direction opposite to that in which the source of light is moved. When a strong light is suddenly flashed by a lens on the sclerotic of a person in a dark room, he sees a distinct image of the vessels of the retina.

Vision with both eyes. Although it can be shown that over the greater part of the field of vision an object cannot be imaged on corresponding ("identical") points of both retinæ, yet we are not conscious of any confusion of images.

This is accounted for partly by the habit of the mind to disregard all objects which do not lie near the axis, partly by the fact that we accommodate only for objects on which we fix our eyes.

Stereoscopic vision. The perception of the third dimension is dependent on the combination by the mind of the observer of the two dissimilar images which are received by the two retinæ, whenever both eyes are fixed on some point in a solid object at a short distance from them. The point so contemplated is the only one which is projected on "identical" points of the two retinæ. All other points are seen double.

Estimation of distance. The distance of any object contemplated is judged of principally by the sensation of the muscular effort which is employed in accommodation, as well as in bringing the axes of both eyes to the requisite degree of convergence.

Hearing.

The process of hearing consists (1) in the production of vibratory movements of the membrana tympani, which are synchronous with the sound-vibrations of air in the meatus; (2) in the communication of these vibrations to the liquid contained in the labyrinth; and (3) in the production of vibrations in all those parts of the lamina spiralis of which the vibration-rate agrees with that of vibrations existing in the liquid.

Sounds are divided, according to the character (form) of the air-vibrations of which they consist, into non-musical sounds or noises, and musical sounds or "tones." Of tones, simple and compound are distinguished. The former consist of simple pendular vibrations; the latter of several such vibrations, which are then called "partial tones." Tones differ in pitch: the pitch of a simple tone is expressed by the number of its vibrations in a second: that of a compound tone by the vibration-numbers of its principal partial-tone. The vibration-numbers of the several constituents of a compound tone are to each other in the relations expressed by the numbers 2, 3, 4, 5, &c. Any compound tone may be resolved into its partial tones by the employment of a system of resonators, provided that among them, resonators are to be found of which the proper vibration-numbers are identical with or approximate to those of the partial tones of the sound to be resolved. Such a system exists in the organ of Corti.

The membrana tympani derives the facility with which it is tightened and its freedom from vibrations of intrinsic origin, and consequently its fitness for its function, from its funnel-like form.

In the communication of the movements of the membrana tympani to that of the foramen ovale, the malleus and incus act as one piece; for the tooth of the incus is kept locked against the notch of the malleus. So long as the membrana tympani is tense when in this condition, the two bones rotate on an axis of which one extremity is at the tip of the short process of the incus, the other corresponding approximately to the attachment of the ligamentum anterius of the malleus. When the membrana tympani is relaxed, the distance between the tip of the long process of the incus and the handle of the malleus slightly increases. It is necessary in order to the efficient working of the tympanic apparatus, that the cavity of the tympanum should be in frequent, though probably not in constant communication with the pharynx. This is insured by the existence of a muscle, the salpingo-pharyngeus, by which the eustachian orifice is expanded whenever, as in the act of swallowing, the posterior faucial arch contracts.

Taste and Smell.

Taste. In man, taste is limited to the posterior third of the upper surface of the tongue and to the border of the anterior third. This region is characterized by the presence (either in the epithelium lining the furrows which surround the papillæ circumvallatæ, or in the epithelial covering of the papillæ fungiformes) of the peculiar bodies (taste buds) which are believed to be the end-organs of the nerve of taste.

It is probable that all sensations of taste may be referred to one of four fundamental varieties (viz., sweet, bitter, sour, salty) and that each of these depends on the excitation of a corresponding variety of nerve-fibre. Taste sensations are much modified by mixture with tactile and olfactory sensations.

Smell is limited to the upper part of the septum, the upper turbinated bone, and the upper part of the middle turbinated bone. This region is characterized by its slender columnar epithelial elements, and by the existence among them of the peculiar spindle-shaped elements, which are believed to be the end-organs of the nerve of smell. In inspiration, so much of the air as is admitted by the anterior half of the anterior orifice enters the olfactory region. The expiratory current is almost entirely diverted by the body of the sphenoid, so that odours of intrinsic origin are but little perceived. The varieties of smell are more numerous than those of taste, and appear to have little relation to the chemical constitution of the gases or vapours which occasion them.